COGNITIVE PROCESSES IN ENGINEERING DESIGN

APPENDICES

CONTENTS OF APPENDICES

Appendix A

Undergraduate Design Study

Appendix A. Undergraduate Design Study

A.1. INSTRUCTIONS PRESENTED TO UNDERGRADUATE DESIGNERS

A.1.1. DIARY INSTRUCTIONS

Recently a NAB funded research project has been initiated within Plymouth Polytechnic which is a collaborative venture involving contributions from the Department of Electrical and Electronic Engineering, the Department of Computing and the Department of Psychology. The general aim of this research programme is to develop software tools which can support the engineer engaged in the process of engineering design. Ultimately it is envisaged that tools will be available to assist the engineer throughout the design activity, from the initial global specification of requirements to the final description of the manufacturable design.

Engineering design appears to be a psychological phenomenon of extreme complexity which is very poorly understood. However, in order that support tools may be developed which are of some real value it is clearly essential to obtain as detailed an understanding as possible of the way in which engineers go about their design activity. It is with this latter objective in mind that you are being approached and your assistance is being sought. As a final year undergraduate you are required to undertake an important design project and to complete this within a specified period of time. Although to some extent you may have started this project already, it is hoped that you are still at an early stage of idea formation, planning and decision making since we would ideally like to obtain as complete an understanding as we can of how your final design evolves.

In attempting to reach a decision concerning the optimal method for deriving information from you regarding your design activity, we became aware of two important considerations. Firstly, we realise that it is only feasible to ask you to spend a small amount of your time in assisting with this research. Secondly, we want to elicit "accurate" information from you in the sense that it is information provided concurrent to a specific episode of design activity. The technique that we decided best satisfied these requirements is for you to keep a "Project Diary" with each brief entry being made whenever you are engaged in project work. The diary - which we will provide you with - will consist of a number of A4 sheets, and it is hoped that your weekly entries will extend to about one side of writing (although this will obviously vary from week to week). At regular intervals diary sheets will be retrieved and examined. We would also like you to attend periodic interview sessions (twice-termly and lasting only 20 or 30 minutes) in which you can clarify or elaborate on certain of your diary entries and any additional information that is felt to be needed from you can be asked for.

It has been agreed that you should be offered some money to encourage your assistance with this research; twenty-five pounds is the sun that you will receive in total. A point which should be emphasised is that the content of your diary will in no way influence the marking of your project. Indeed, your supervisors will not even see your diary until after your project.

A.2. EXAMPLE TRANSCRIPTION OF DIARY AND INTERVIEW DATA

A.2.1. TS'S PROJECT DIARY

DIARY FOR WEEK STARTING 22/10/86 AND ENDING 28/10/86

Activities

I thought that I understood the operation of the system that I am designing, but it is part of a larger system which controls the DMA operation. Questions on HOW the system controls the DMA unit have been raised. I am now trying to understand what controls the DMA unit and this involves interaction with the company who initiated the project.

Aims/Objectives

I aim to expand my existing understanding of the DMA unit operation- and to understand how the rest of the 'system' controls the DMA unit. Perhaps I can incorporate some of the control logic into my project and hence make it a more attractive solution to the design problem

-Get written answers to my questions.

Problems/Constraints

I need more information about the graphics system to which the DMA project is associated. This involved getting the information from the company who initiated the idea. My understanding, and queries on the operation of the system must be clear and concise, so that my questions can be answered in a similar manner - I am writing my questions down and posting them as well as telephoning and asking questions.

Decisions

Write to Company C----- for further information.

Write down how I think the system works.

Evaluate what parts of the overall system could be included in the project.

Get on with written project introduction while waiting for information.

Methods

It is important when conveying information, or asking questions that both parties are sure of what the question is. I am telling W how I believe the system works, and raising questions. That way they can tell me if my understanding is at fault, or give me information to complete the story.

General Comments

I feel that I really understand the DMA operation - what it does, and should do, but I don't understand how the rest of the 'system' tells the DMA unit WHAT to do.

This has lead to questions on how the unit is controlled, and can I expand my designs to include some of the control circuitry, hence make the end product more adaptable to alternative uses.

This has rather set me back in my design since I was happy with a functional diagram of the DMA unit, but now I need to consider control and extra circuitry outside the area previously covered. All the work so far is valid, but must now be set aside, for this new area to be explored.

DIARY FOR WEEK STARTING 29/10/86 ending Tuesday 4/11/86

Activities

Self familiarisation with the 'Bleasdale Computer System' with regard to using it as a word processor for writing the project report.

Familiarisation with the APOLLO CAD system which will be used for all my design circuit work and simulation. Waiting for postal information from a company.

Aims/Objectives

Start writing project report - at this stage an Introduction could be written to clarify the project objectives with all interested parties.

Get an initial 'block diagram' or functional diagram on paper with connections which may be necessary , so that I can deal with 'modules' of the project, rather than trying to do the project as a whole.

Problems/Constraints

1) I am waiting for some information from the company who initiated my project regarding how the system deals with specific problems i.e. start-up, and updating information. I asked them questions and am waiting for reply.

2) Non familiarity with the commands on the CAD system means that I am having difficulty setting up 'files' on the system.

Decisions

Write introduction on word-processor

Do simple functional diagrams on CAD system.

Get more detailed diagrams on paper.

Describe more fully how the DMA controller works and reacts under all conditions of operation.

Methods

I am trying to keep all areas of the project in small 'modules' e.g.:

report - do intro.

project - do functional diagrams.

Later I can elaborate on each module as I am ready or information is available.

General Comments

Not much direct project work has been achieved this week owing to the need for familiarisation of the systems I will be using during the project.

Now that I have a 'feel' for the word processor and CAD system I should be able to do some project work using these tools, and gain operational experience of the equipment.

Delay in postal information is not unexpected due to a postal strike in Gloucestershire - the source of my information. The data is not particularly vital since I have been able to work on other areas of my project, so I haven't tried to phone or speed up the data.

DIARY FOR WEEK STARTING 5/11/86 AND ENDING 11/11/86

Activities

This week I've spent all my time (Project time) on the word processor.

I've read two books on documentation and documentation developing methodology. I have written a basic 'system' explanation explaining where my DMA control unit fits into the system. The layout takes a long time at the moment because I am unfamiliar with the commands.

Aims/Objectives

Aim to get a full introduction to my project, with regard to how it fits into the rest of the 'graphics system' and an explanation of how it works and is controlled must be done as soon as possible for the company who have an interest.

Problems/Constraints

It takes a long time to put my explanations into the word-processor and get the desired results.

Decisions

Decided to work solely on the introductory chapter, and not do practical work until this important section has been done.

Methods

Write out information by hand first, then enter it, and modify later.

General Comments

I don't feel that I'm getting on with the project, and time is passing by too quickly. I feel that I must get this chapter out of the way before I can get fully 'under way' with the practical side of the project.

DIARY FOR WEEK STARTING 12/11/86 AND ENDING 18/11/86

Activities

Completion of a project introduction written using a word processor.

Block diagram of DMA unit started using the APOLLO CAD system - have drawn one block.

Aims/Objectives

Aim to get block diagram completed next week so that I can see an actual achievement. A milestone of the project on the CAD system.

Intend to write report on DMA unit with more technical detail and state aims of the project.

Problems/Constraints

Very slow to use the word processor, and achieve required output format. Although I am now quite used to the system and so getting quicker.

The CAD software is about to change so detailed circuit diagrams cannot be designed.

Decisions

Decided to make a 'milestone' for the project - aim to complete block diagrams next week.

Methods

Familiarity is the key to becoming proficient at use of the CAD system (and word processor) so I shall try to use this equipment as much as possible during project time - even if tasks aren't critical.

General Comments

Having completed my introductory information on my project, I feel I have achieved something and this has revived my motivation in the project.

I am not able to spend as much time on my project as I would like due to other work which is necessary. I feel I would like to spend more time on the project, to get more achieved and get underway more - I feel I am still at the beginning - hardly started.

DIARY FOR WEEK STARTING 19/11/86 AND ENDING 25/11/86

Activities

Drawn two library cells on the CAD system. These are basic functional blocks for the system, which are a high level block in the hierarchical design process.

Aims/Objectives

To complete the functional block circuits of the DMA unit so at Christmas I can take a block diagram to Company C----- and show them my intentions for the design.

Problems/Constraints

I cannot make the functional blocks explicit to component level because the updated library which I must use hasn't arrived at the Polytechnic yet.

Problems with wiring buses due to special component and definitions required by the CAD system.

Decisions

Must get a functional diagram of the first part of my project completed by Christmas so I can show Company C-----. Think about internal components for blocks so when the library that I need appears I can use it.

Methods

Read Apollo CAD system handbook for wiring the block diagrams together, to overcome wiring buses problem which I have encountered.

General Comments

This week's problems have been due to inexperience on the CAD system and have been useful in understanding how to use the CAD tool.

DIARY FOR WEEK STARTING 26/11/86 AND ENDING 2/12/86

Activities

Having defined my functional blocks I have now linked them together with the wires that I expect to use in the system. All CAD system work.

Aims/Objectives

I have decided that my project report will require a detailed analysis of how the graphics system works and controls the DMA. This will be written work for the project.

Problems/Constraints

Due to a lack of information from Company C----- a few questions and alternative design paths have arisen which need sorting out. I shall design how I think best, but keep my options open.

Decisions

Will go and talk to Company C----- during the Christmas vacation.

Write about system in detail for project.

Methods

When my functional block diagram is complete and agreed with W it should be a 'simple' process to complete all the circuit design within these functional blocks, since there will be no ambiguity in how the system should function.

General Comments

I didn't really realise that the system analysis would be such a large part of the project, and I have now decided that it will probably present the most difficult stage of the project due to interaction with Company C----- and deciding on the best methods of achieving the best end result.

DIARY FOR WEEK STARTING 3/12/86 AND ENDING 9/12/86

Activities

Writing down and defining how the graphics system will work, has been the main area of progress this week.

Aims/Objectives

I aim to write a concise analysis of how the DMA unit is controlled and how it works within the graphics system. An introduction to this has already been done.

Problems/Constraints

Still no news from Company C----- so my options on the functional block diagrams are still open. I shall go to see them during the Christmas vacation.

Decisions

No new decisions made.

Methods

I have mainly been studying my original notes on how the graphics system works, and expanding the detail in some key areas, such as the layout of the Physical System memory, as regards memory mapping.

General Comments

Because it is now getting to a stage where I need to finalise my block diagram with Company G. I am going to have to discuss with them exactly what they need, to decide which design options to take for my final block diagram. Two main methods have been identified with concern to 'ADDRESSING'.

The graphics processor seems to be the only 'master' with respect to loading the address counter of the DMA unit, and so the address data need not be read through the I/O ports, thus giving a faster load time.

If I load the address counter through the I/O ports the address could be loaded from either the graphics processor or the system processor - but why might this be done?

DIARY FOR CHRISTMAS VACATION AND FIRST WEEK OF TERM

Activities

With the 'top level' block diagram completed I know what signals are coming into the DMA unit from the rest of the system, so I can design the control logic. Designs for I/O port with comments on advantages of two designs.

Aims/Objectives

To fill out the 'I/O port' and 'addcount' blocks with gate array logic components, and to make some initial designs for the control logic over the next few weeks.

Problems/Constraints

No problems with 'I/O port' or 'addcount' blocks so far except for the vast range of methods available to implement them - so design selection is biggest problem.

Control logic definition is difficult since I am using signals which may well have been 'conditioned' for specific time delays and conditions earlier in the system design.

Decisions

Use 'DOC', the Apollo system word-processor for report - already transferred one document to the 'DOC' processor from the Bleasdale

Must have substantial circuit diagram and design by 5th Feb when external examiners will be looking at the projects.

__Methods__

Looking at data books for I/O ports, and their implementation has led to my design of I/O ports using latches and tri-state buffers.

Counter is a basic binary counter, which again is designed by comparison with binary counter designs already implemented in commercial ICS

__General Comments__

See insert sheets for ideas and idea development notes.

Later I will need to consider testability of the blocks, although the their inputs and outputs will be accessible externally to the DMA chip, so can be tested without extensive test logic being built into the system.

Pin-out will be a consideration which should be discussed with Company C----- if any production chips are to be made. Also care must be taken if there are any time-delay critical areas of the design.

DIARY FOR WEEK STARTING 14/1/87 ending Tuesday 20/1/87

Activities

Aims/Objectives

Problems/Constraints

Decisions

Methods

General Comments

Following recent correspondence with Company C----- I have decided to include a second address counter to allow two address locations to be stored.

Control Registers are another useful facility which I would like to include. These registers must be read from and written to by both the system processor and the graphics processor. These will be implemented in exactly the same way as the I/O port since it is a register.

DIARY FOR PERIOD STARTING 21/1/87 AND ENDING 10/2/87

Activities

Design and verify (prove through simulation) the I/O port. I shall complete the test routine for the verification today - this is just a simulation of the I/O port in operation.

Next I shall design the 32 bit address counter.

I am reading data books for information on commercially available counters for ideas on implementation of synchronous counters.

Aims/Objectives

I aim to spend less than 2 weeks designing the counter - and to prove it. The counter should be a tri-state device so I can have several counters, independent of each other on the system. Completion aim for counters - 24th Feb.

I aim to have broken the Control block into subsections and have definite plans for implementation shortly after having completed the counter (beginning of March, say).

Problems/Constraints

Problems with the design and verification of the I/O port have mainly arisen due to my unfamiliarity with the CAD system (see Gen Comments). Now that I have gone through a full design and verification of one 'block component' I feel confident that there will be no (or very few) delays due to being uncertain of how the CAD system works.

Decisions

I have decided that I will only make one design for the DMA unit - not 2 as originally hoped. This is due to the slow start in getting the CAD system fully under my command, and the relevant component library only appeared this January - hence no design process was completed before then.

Methods

Through continual reference to the Apollo User's Guide and 'Idea' system reference manuals I am becoming familiar with what the system is capable of doing, and how to use the commands to achieve the desired effects. There are a very extensive number of commands, and also some faults on the CAD system.(See Gen Notes - PANELS).

General Comments

Enclosed are:

New diagram for CELL and REGISTER - update necessary since I used a CMOS component before, and the logic levels on the input are TTL, hence the system would not have worked.

Verification run (timing diagram) of CELL

Investigation into start up (see timing diagram). This was done for interest to see how long the system propagation delays were, and to calculate what time the CAD uses in its simulation. Typical time delays are used.

Investigation into tri-state operation.

Investigation into data direction reversal.

All information confirmed that the system uses typical propagation delay times for simulation. Also that there will be no problems due to propagation for the circuit under operating conditions of 10MHz data rate.

DIARY FOR PERIOD STARTING 11/2/87 AND ENDING 18/2/87

Activities

Verification of the I/O port (as done last week for the CELL unit).

Evaluation of different circuit implementations for synchronous counters which are available as TTL logic components, e.g. 74193 binary counter.

Aims/Objectives

Aim to have completed design of counter before now.

Aim to get the counter designed by next week (24th Feb).

Problems/Constraints

Problems in verifying the I/O port 'system' because I have organised my files in the Apollo system such that each unit can be run individually, but cannot be combined to run as a group on system. (See NOTES).

Decisions

I have reorganised my files within the system so that everything will work in harmony.

Methods

The transfer of files around the system involved defining which files within a specific system directory are important for allowing the system to simulate designs properly. I could then just transfer the necessary files, thus saving a hell of a lot of time.

General Comments

Problem of the hierarchical design not working on the APOLLO CAD system was due to my understanding of the system. I wrongly assumed that files could interact to get information from each other if they had the same name. This was not the case and so although each individual input could be tested i.e. CELL, the total I/O port system couldn't be tested because it was ignorant of the workings of cell.

By putting all information about CELL into a single directory everything worked OK.

DIARY FOR PERIOD STARTING 19/2/87 AND ENDING 24/2/87

Activities

Full verification of I/O port - timing diagrams enclosed.

Get a 32 bit address counter designed on the Apollo system.

Aims/Objectives

Counter should be designed and verified over this next week.

Completion by 3rd March?

Problems/Constraints

Following the files reorganisation last week I envisage no problems other than evaluating the best design for a 32 bit counter.

Decisions

Complete counter by 3rd March (next week).

Methods

Read data on manufacturers counters, e.g. 74193.

Look at counters implemented by other designers using the gate array.

Decide what offers the functionality required and use it.

General Comments

I/O port verified:

Information enclosed:

Simulation program to give full verification.

Timing diagram of whole verification.

Highlight of counting and a short error state which occurs due to different propagation delays due to rising edge or falling edge propagation delay of the cell. These should present no problems during operation since they are very short (1.2ns) and all data is triggered on a clock edge.

Highlight recovery from tristate condition.

Highlight activation of tristate condition

12ns propagation delay through the I/O port

Effect of shifting data transition (i) 30ns after clock edge (ii) 10ns after clock edge. No effect on operation as expected.

DIARY FOR WEEK STARTING 25/2/87 AND ENDING 3/3/87

Activities

Evaluate counter designs used on commercial components to determine 'best design' for use on the DMA unit as a 32-bit synchronous counter.

Aims/Objectives

Aim to have designed the counter today (Project day, 3rd March).

Verification timings.

Problems/Constraints

System is shut down on project day (Tues. 3rd March) for half a day (1.00pm onwards, therefore unlikely to complete the counter).

Decisions

Will design on paper and in my mind, then, using existing programs for verification on I/O port, develop the verification program for the counter ready for efficient use of the system when it returns.

Methods

General Comments

32-bit counter design.

See log-book: Tuesday 3rd March '87.

A.2.2. TS'S INTERVIEWS

INTERVIEW WITH TS ON 4/11/86

DS: Can you tell us what your project is on?

TS: It's a DMA controller gate array and what..

LB: What is DMA?

DS: It's Direct Memory Access.

TS: It started off - the company I was working for last year have got a new project going on, and I asked if they had anything going that wanted doing ... and their existing system .. or their newly designed system .. has got DMA controller designed in discrete logic and it's not very good : they are complaining because they are having difficulty - timing problems and things like that... So what they asked me to do is to modify it and make it quicker, easier to use, and perhaps make it cheaper, or at least keep the cost the same anyway by doing it on a gate array - so I thought I would. Uh, so to start with I've got a discrete design already done; another chap up there did it .. so I've got to change that to fit on a gate array .. really I'm totally redesigning it..

DS: So essentially what he's doing is transferring as board full of components .. electronic integrated-circuits into one chip .. actually it's like a semi-custom type approach isn't it? .. (TS: That's right, yes) ..where the companies have chips available which are complete apart from the connections, and then you specify the connections and they make them up, and essentially you put board level components onto one chip. It saves a lot of room and it makes it cheaper and it makes it more reliable and normally a lot faster.

LB: How are you going about attacking this initial problem?

TS: Firstly, I've got to meet the specifications of their existing board first, and then I've gone ... I've looked at their board and seen how they've done different things: why they've put certain logic blocks in and so on. Now I think I can do it in a different way - better than they've done it anyway, so I've made it clear to them that I want to redesign it .. and they seem fairly happy with that.

LB: Are you going to use any of the existing logic blocks at all?

TS: Yes, because a lot of it is .. there are characters in it .. when I sussed out the block they wrote the same .. it doesn't matter how you design a circuit around it assuming (unintelligible here) which again is a self contained block .. really you can't make any difference to it .. so it's just a small amount of change to the control logic.

DS: And this will make things better as far as you're concerned?

LB: In terms of performance?..

TS: Yes.. I should be able to ... Let me start again .. we've got a hazard state on their existing system in that when we assume there's a read from memory - you've got your block of memory which is doing the memory access - it has to .. you read data through, and after a certain length of time has elapsed the DMA controller forgets what it is doing.. and so software have to do is keep reminding it that it's taking data through. It only came about because of a hazard state within the discrete logic, but it's caused software a hell of a lot of trouble because their having to think well 'how long is this going to take'..

DS: So you've thought of about a solution to this type of problem?

TS: Yes, I've thought about it but they also had a solution themselves, which involved just adding logic to what they already had, but I think redesigning the whole system would be better. That's what I'm trying to do.

DS: OK. Now this area is relatively new I gather, so how have you obtained information with regards this, how have you researched and things like that.

TS: There are a lot of DMA controllers on the market, but the special thing about this one is that it's a 32 bit which is bigger than the normal device. So what I've done is looked at the usual 16 bit devices and seen what facilities they offer.. there are things like chaining into blocks of data ... just things like that. I've just looked at what the existing ones can do.

DS: Now your supervisor which presumably is P .. how much help, feedback, that type of thing, have you had from him, and if you haven't had any, have you had any other sources of information that help you design what you are doing.

TS: I haven't had any other sources of information; I've just gone to P and said what I have done so far. I haven't talked to anyone else about it. At work, obviously, I had the initial drawings .. and I've phoned them up and written to them to find out exactly how the rest of the system works..

LB: Can you elaborate a little on what IS the rest of the system?

TS: The whole system is a new graphics terminal by this company Company C-----. It's got UNIX on it and all types of fancy bits and pieces that they don't usually have..

DS: Similar to the SUNs but probably a bit more (unintelligible here).

TS: That's right. And so.. when I refer to the whole system, I mean that; what I'm doing is just looking at the DMA which is a very small section inside the system on the graphics processor side of it. Most of the time that's redundant, because the thing's just displaying a picture - and it doesn't have to think about that, it just does it on its own .. but when you want to change the picture the rest of the system talks to the graphics processor and says 'right, draw another line there' .. so then the rest of the system tells DMA 'right, get some more information from your memory; tell the graphics processor to put a new line on the screen' .. and that's what I mean by the rest of the system.

LB: So it actually has a controlling function?

TS: That's right. The rest of the system actually talks to the DMA controller and says when to operate and what to do. The one I looked at it before was a discrete function.. was..(coughing renders this section incomprehensible).. as a board and just said right I'm copying that, and forgot about how it was controlled. I thought, well as long as I could link up with what they'd got already it would work. What P wants me to do is look a how they control this DMA unit and try and incorporate some of the logic from other areas of the system and put it on the controller. So, in effect, I'm not directly copying their stuff, I'm improving it more perhaps.

DS: So you are taking other areas as well. You're using the full capabilities of this?..

TS: Trying to, yes. I think ... It's one of those things where you can keep going.. I can incorporate a small amount of control logic for one area - just the graphics processor - and no doubt more areas will come up which I think 'well perhaps I could put that in as well' .. so I think its a bit of an ongoing project. That's really why I've split it into two. I think that definitely I will finish the direct copy - more or less - and probably won't finish the other one. But if I structure it in a modular way, I will do the graphics processor .. my controls for that come into the rest of the unit (unintelligible here) .. so if I build it up in little modules, then it doesn't matter when I run out of time - it will be in a working state.

LB: What specifically are you working on with the APOLLO CAD system at the moment?

TS: I'm using the APOLLO CAD system to actually design, because a gate array has a limited number of functions.. you've got a variety of ways in which you can implement things. The CAD system has got the library of everything that's available to me. So I'm using the CAD system to build up a functional block, then fill in the blocks and ignore the information between. Then the CAD system should be able to arrange that into a proper way. I'm not exactly clear on what it's going to do for me yet, since I only looked at it today..

DS: What prompted you to actually do this project in the first place? Was it you wanted to do it or what .. was it an idea and you thought that you'd like to do it?

TS: No. I wanted to do something that was interesting and new. I'm not very interested in power electronics or motors.. I was working for a digital company anyway.. so I asked them just on the off chance that something was available.

DS: And they said 'We have this', and the specification and everything else came from them?

TS: Well sort of, yes. When I came back for this term we were told about the APOLLO system and how you could do gate arrays because P was doing his gate array stuff .. And when they heard about gate arrays and systems like that - 'Oh great, we can make use of this, (this is money .. really)' .. I think that made them interested..

DS: From what point of view are you interested in it? I mean are you expanding your knowledge in an area that you don't have much knowledge in, or what?

TS: No.. I feel confident with digital electronics .. all the design work I was doing for the company was in digital electronics .. perhaps I shy away from the analogue .. so I'm trying to escape from that..

DS: So you're escaping from having to do an analogue project?

TS: I think it is, yes.

DS: You are going into an area which you understand - which you have domain knowledge in?

TS: Yes, but it's also .. I've seen gate arrays and people comming along to the company to sell gate arrays and saying this is the thing of the future .. and the bosses where I was working, when they heard that we have gate arrays.. 'Ah! what are they what do you do with them and how powerful are they and how cheap can you get them!?'.. because they are using very large ones for custom jobs themselves - but that's in a separate department really .. the development department obviously didn't really get involved - they didn't Know about it .. So when this came up and they found out they are fairly cheap they became interested, and it all followed on from there; if they're interested then perhaps it's something of the future and I ought to be interested.

LB: You were emphasising modular approaches that you are working with; when do you think you will get a functional diagram sorted out.?. I was just wondering how you see your actual functional decomposition progressing?

TS: For project number one which is a direct copy, I have already got a functional block because there are only three blocks in it - so that was fairly easy..

LB: Now that you've suddenly found out about the whole system..

TS: That's right ... As far as project number one is concerned I've already got that, but as far as project number two I'm going to have to look at when .. I'm waiting for some information from the people; when that comes back, I can see perhaps what bits I might be able to put in .. or not.

LB: So at the moment you're liaising with the company quite steadily and waiting for information to to arrive?

TS: It's only one letter.

DS: It's early stages yet?

TS: Yes as far as that's concerned, yes. That was a bit of a surprise to me a couple of weeks ago .. I thought I had to go into this other area or perhaps it might be useful if I went into this expanding area..

DS: Now you are obviously using the CAD system, but I don't think there's any real other choice - you can't design gate arrays by hand. How much research have you actually done in this area of designing gate arrays, DMA controllers in general, and that type of thing? What sources have you used - just P, or is it too early in the day at the moment to say?

TS: When I was working I was doing a lot of digital design and I worked down at gate levels then - everything was designed at gate levels.. so I was given the specification and told 'Right make something that will do that' and I was designing from gates say.. so I've done about eight months of design down at gate levels.. so what I intend to do.. the way I'm thinking is that if I design anything at the gate level - the smallest level - I can just do that on the CAD system.

DS: You have a pretty good domain specific knowledge of this (TS: Yes) .. it won't necessarily be much of a learning process for you?

TS: Not really, no, it shouldn't be. This is much bigger than I've ever done anything before..

DS: Ah, so it is new for you in that it's big, but it's not new in that you are applying knowledge that you already have to a new task?

TS: Yes... You have weeks like this when it's just getting information and getting familiar with the system - you don't really feel that you've done anything..

DS: It still takes your time up doesn't it?

TS: Yes it does..

LB: Won't the way that you design the control circuitry have any effect on the way you design the DMA unit?

TS: There's a small amount of control circuitry in the DMA anyway areas of control, that will effect the rest of the system because I'm going to be taking more and more signals from other areas of the system - the way that effects my project is that it puts more pins on the end device and makes it more expensive. What I'm trying to do is to keep it cheap..

DS: So that's really a constraint in your design?

TS: It is, yes, it's a self inflicted one really, because.. Forgetting the number one level which is the direct copy, if the number two level is to be accepted it has got to be fairly cheap, and the main cost as far as I understand it, with these gate arrays .. the pin out is quite a substantial cost and then how complex it is inside is a secondary consideration.

DS: Are there any other major constraints in this project, does it appear to be a cost one or..

TS: Yes, I think it is a cost one in that if I can't sell it .. if the company I was working for aren't interested in Mark one or Mark two, then it won't ever get built .. it's too expensive for the Polytechnic to put forward .. so at the end of the day if it's not cheap enough or it doesn't meet the company's requirements, then I will never get physical result out of it - it will always be timing diagrams and so forth out of the CAD system. So what I'm trying to inflict is: keep number one cheap, simple, small, and number two, keep that as small and simple as possible as well and keep it so that it is totally testable as well .. there's no point in building something and missing out all the test circuitry and thinking, well that should work, and if it works on the CAD system it's bound to work in real life .. that would be fooling myself.. that would mean that the thing, if unreliable couldn't be tested - they wouldn't be able to find out what was wrong - so I can't take short cuts to make it cheaper.

INTERVIEW WITH TS ON 4/11/86

LB: How's it going then?

TS: All right. I've actually done quite a bit since I saw you last on the gate array on the CAD system..

LB: Can you tell us a little about what you've been doing since that last lot of information I got from you? You gave me a very helpful written introduction to you project - with a block diagram that enabled me to get a good model of where the DMA was in the system. Really you seemed to be just getting used to the CAD system and the word-processing system on the Bleasdale..

DS: You're not using the word processor on the APOLLO then - DOC?

TS: No, I wasn't really aware of it .. this is the first time I've heard of it.

DS: It's marvelous, incredible ..

TS: What's it do that's different then?

DS: It's WYSIWYG, 132 columns by whatever .. and you can send it out to the laser printer in the GTB .. Anyway the important thing is that you tell us about what you've been doing.

LB: Yes. I assume that you've started your redesign of the DMA unit by now have you?

TS: Well I'm still .. so far ... I've sent a letter to Company C------ you know about that - I haven't received any written information back but I'm still able to work because from a phone call they I made I was able to get quite a lot of information off them. So what I've done is to carry on with the design that was for Company C----- on the information that I have already. So I have now got a functional block diagram similar to the one you have got in there actually on the CAD system which is wired together. A couple of questions have come up.. alternative design ideas have come up with regard to placing of the functional blocks - such as .. it's got an I/O port and an addresses counter and a bit of control logic that controls the two systems.. now as far as I understand the address counter can be loaded from - is only loaded from the graphics processor - so in my block diagram design I can put it in one of two places: either load it directly or through the I/O port .. so that's a question that as come up with the design.

LB: How are you evaluating the possibilities there are?

TS: Well what I want to do is get in touch with Company C----- again - that was one of the questions I asked them: How do they load the address counter and why - which I haven't found out - so what I've done is done two block diagrams: One with loading the address counter through the I/O port and one with taking it directly off the graphics bus. So I've got two block diagrams now and I'm just going to have to take them up and see them next week.

LB: So you're actually going to visit them are you?

TS: Well my Dad goes past there every day so I just as well drop in.

LB: That will be a good idea .. so you can spend the day there..

TS: That's right, I can spend quite a long time talking to them one to one..

LB: It looks like they've taken a long time replying to your letter?

TS: Yes there's been a postal strike but that was only two weeks and it's over a month and a half since then - but since I've been able to get on with other stuff I haven't really needed the information.

DS: So what stage are you actually at then?

TS: Well now I've got a block diagram.. (LB: or two block diagrams really ..) .. yes, two block diagrams of the existing system. I've also decided to write in more detail about the existing graphics system because that has been my main problem.. and finding out exactly what Company C----- want and I've met up with alternatives like I have just described .. and really if that was written out in full detail... I need the functional specification in more detail than I have got because I've come up with the idea that I can load it from the graphics processor or the system processor.. these questions have got to be written out in full.

DS: How much of the actual design of the various blocks inside this DMA have you looked at?

TS: Inside the DMA - I haven't given it much thought. I've talked to Mr J----- about it, just quickly. The thing is, within the blocks it's fairly simple standard stuff: like the I/O port is just a register - it's just D-types - which are on the gate-array system .. there's blocks, units .. similarly the counter - that's just a set of latches. So because I've designed those things before, I'm just confident enough to have not thought about them much at the moment.

That's another problem with (unintelligible here) in that the CLA 5000 - which is the gate array system that were using - has got a new library out which we haven't got yet, so I haven't been able to go into the blocks and put components in, so that's why I haven't really thought about it much. So really all I've done to date is made the block diagrams and to understand everything.

LB: Are there any other blocks inside the DMA aside from the ones that you've mentioned.

TS: No. Not yet.

LB: But there are going to be?

TS: Yes. Again .. I haven't started this second phase, which was the idea of more control, and that's because I need the information from Company C-----. Having said that, I've thought about it, because we came up with the idea that you need control status registers which takes information from the graphics processor, tells it what data's where in physical memory, then that information has to be told to the system processor that then tells it to the DMA. So I could short cut that loop by saying .. take the information from the system processor - the one that knows where everything is in the physical RAM - and tell that directly to the DMA unit and that should cut out quite a lot of time from the system processor.

LB: But that is rather the phase two of your project?

TS: That's really going to be phase two.. unless Company C----- are going to start giving designs that they've already done.. and I don't think they will, because they are working on a modular basis themselves in that the bit that I'm designing is add-on - if you want that you pay x-thousand pounds more and they chuck the extra components in on the board. So they really want to keep everything hoe it is at the moment. I've sort of discovered that I have got to really keep too what they want and not expand my ideas too much as far as they are concerned .. I Don't think they would be very interested..

DS: Is it faster than their's is?

TS: It will be faster than their's, yes. They've got problems in the high speed clocks, and their block transfer of data, and they've got a software problem as well in that the system forgets what it is doing. The data in the display file, which is the picture data, consists of a command like Draw from x to x, and then the parameters that fit that command like draw and then the locations, and then the actual graphics processor reads that and says now I've got to draw something and it goes of and does a subroutine sort of thing. But at present the DMA unit is working on clock pulses - it just counts time rather than waiting for a new signal that says right, carry on we need some more information.

DS: Synchronous, you mean, as opposed to asynchronous?

TS: Yes. So when it goes off into its subroutine, if it goes off for longer than - I think it's a few microseconds, I'm not sure of the exact time but it is a fairly short time .. it's about eight cycles of a clock - then the DMA says right I've finished, I obviously haven't got anything else to do, I'll give the bus back to the system processor, and so it loses all control and you can't get any more data without stopping the system processor again and then going back to the start location and going through the table. So they've got problems in that which I hope to iron out. That is really a speed problem and also a design problem. They get by with it - with what they've got - it just means the software has to keep reminding.. keep kicking the DMA unit to say keep awake you're still doing something. They're struggling with what they've got, but they don't think they're redesigning it, they're just leaving it.

DS: Have they actually done a little redesign - piggy-back boards and sort of thing?

TS: Yes they've actually got one running. They're just testing out whether it will transfer data - pictures and what they look like on the screen..

DS: So this is a new product of their's, is it?

TS: Yes, it's a brand new product. When I left in the summer that's what they were doing .. they hadn't actually got any pictures on the screen because it's a very high resolution thing and they haven't done anything like it before. So it's a brand new product..

LB: So you going to get to work on that next term I assume; you won't be able to do much over the holiday will you, except visiting W?

TS: That's right, I've got to visit them and write out perhaps some parts of that introduction that you've got in more detail to outline the problems I've met. But as far as actual implementation on the CAD system I've only got a block diagram ... and then I reckon it will be downhill from there: once I've finalised that and got all my problems sorted out it will just be a case of filling them up - which as I've already described is just a case of fairly simple components.. to put them together. On the block diagram level you do have to define what wires you are going to put where, so I already have a loose design of how many wires are coming into the system from outside into my final chip.. so I've got a bus coming in from the system, so I'm pretty well defined as far as the chip goes.

LB: How have you been able to define that so well? From your existing knowledge of what the system looked like?

TS: Yes. Did I show you what information I've had from W already?

LB: No you didn't. I don't suppose you've got it on you now?

TS: No. What I had was a circuit diagram of their existing DMA unit - the one that works but isn't ideal - so they asked me to just match that.. so looking at it at first view, all I've got to do is copy their stuff, but in fact that's not a very good idea - they're using discrete logic, they're using components because they're available and cheap, whereas I can use anything I like because it's all defined, within reason, within the gate array, so I've got much more freedom than they had - so I'm less constrained.. so I can do things that they couldn't do. I think that's why they've met this problem with the timing and having to kick the DMA unit now and then to remind it that it's still doing something.

DS: At high speed you see, you're very susceptible to delays and things in various components 'cos nothing works in zero time, and there may be just one critical path in the system that's to slow and that may cause all the problems. So it's a redesign but you are not really constrained by that are you?

TS: No not really - (unintelligible here) very fast with a gate array because everything's al together.

LB: So reducing it to one chip is going to increase the efficiency?

TS: Definitely.

DS: Also when you use standard components you see.. say as an example you he a standard component and it gives an output and you want the inverse of that output, now if you use a normal component you have to use an inverter, but with a gate array you can just select the actual non-inverted output .. you see, make the component with a non-inverting output or an inverting output or whatever. So you can manoeuvre lots of ideas and avoid unnecessary components just by doing that.

LB: A lot of your work next term is going to be in the APOLLO lab..

TS: Yes, I was determined it was going to be this term but because the library hasn't been there there hasn't been much point in doing it. It was supposed to be here in October. Mr J----- went up last week and they thought they'd given it to the Poly.

DS: Can you use the existing library?

TS: I could as far as working out speed of components, but when the new one turned up I would have to redefine all my blocks.. so there's no point. I've discussed with Mr J----- what's involved ad we've reached a conclusion that it's fairly simple stuff inside the functional blocks so there's no point in going ahead and doing those - and having to repeat the process later on - when we're fairly confident it's going to work anyway.

DS: Just a question on what you've actually done. So you're essentially implementing a board-level product as a gate array .. you've said it will be faster.. have you thought of anything else to do. What other options are available at this time. Mr J----- said something about adding extra stuff .. is it significantly faster .. are there other things that need improving?

TS: I haven't looked at increasing the speed specifically. I know that they've got to their graphics clock which I believe is around ten mega-hertz and it's not a fixed frequency, it's a varying frequency .. so I've got to work on edge triggering. Ten mega-hertz is not especially fast for a gate array - increasing the speed I don't think will make much difference. An area that did appeal to me to start with was to expand the buses. Instead of having a 16 bit bus, take a bigger bus - a 32 bit bus. In that case they could use a different processor than the one they've got now - there are others available but they cost more. Then also go into memory management on board the chip and again that would speed everything up because you wouldn't have to convert something from a ... you've got your large storage system which then converts onto a small storage system.. so you've got one storage location in a big system , you then convert it onto another memory location in your (unintelligible here) section and then you read it out. Well if you had memory management, you could say right that's at that location in the big storage which is slow to access, and right we can dump it over here but call it the same memory location and then everything can refer to the same memory locations. That makes things a lot more simple for the software people. Is that the sort of thing you were after?

DS: Yes.. It only works in one direction .. this DMA thing doesn't it?

TS: Yes

DS: From the systems side to the graphics side..

TS: Yes.

DS: Is there any reason for that .. I mean it's just one thing I saw .. I thought DMA controller, it goes in one side and comes out the other. Is this a specific feature of their particular type .. does it have to do anything else? It doesn't actually transfer from memory to memory in the systems side?

TS: No it doesn't. Well you've got a sort of memory after the graphics processor in that you've got a physio-RAM - that's a high-speed memory - as far as I can understand that's only ever written to it's never written from..

DS: Unless it's a graphics operation which is doing (unintelligible here)..

TS: Oh yes, in that case .. but as far as coming from the system memory down to the graphics it's only single direction..

DS: And that's mainly command writes to the processor, so it's small blocks of data it's not vast pages and pages of memory?

TS: It could be pages - they do envisage a problem..

DS: I'M just trying to envisage the problem of the screen dumping to the memory and I don't see how you do it.

TS: So like you've got a picture on a screen and you want to dump that or take a print of it, what do you do? Good question.

DS: Well that's neither really here nor there so.. You're at a stage where you've designed, how do you see the actual design coming on as soon as the library comes and the information from the company arrives. Do you foresee any problems with your design or is it too early at the moment to think about that?

TS: I don't foresee any design problems. I'm fairly confident on how counters work and how registers work so I'm confident in that I can get the design done. The problem that is looming ahead is how to test the thing. Now testing has got to be done on board. The test methods have got to be designed at the same time as I am designing the circuit. So I don't wan to have to put loads of extra legs onto the chip to say right test: is the I/O port working; does, when I put some data in one end, the same data come out of the other end. So I'm going to have to test it and I have to think about that. I've given it a bit of thought in that it shouldn't be to difficult to test my I/O port or my counter, which are the two main blocks that actually do anything clever, because they are just in one side from a bus and out the other side to a bus. So that's pretty straight forward.. just through information - when you put something in one end it should come out the same the other end rather than having complicated (unintelligible here) in between. I can see that the testing is going to be a problem that I'm going to come up against next, but it's no worrying me too much at the moment.

DS: Have you done much research into this business of testing?

TS: We started a series of lectures about three weeks ago .. so we're getting lectured on it..

LB: Is that proving useful?

TS: It is in that they tell us about one-hundred percent testing of the system - how it can take several years .. just to test out a microprocessor you'd be there for a million years to test every possible configuration. So you have to break it up during the design process .. so I'm aware I've got to design in a test algorithm ... (unintelligible here) out faults is something that I've never really heard of before - they've come up through the lectures. So I think the lectures are useful.. I know the CAD system does some sort of testing on own anyway..

DS: Just by the way. Your DMA controller - will it be software compatible with their's, will it have exactly the same memory locations or will they have to rewrite things to work it? Will you essentially take their board out and put your board in and it will work?

TS: I hope so, yes.

DS: So it will be the same from the software point of view? You will write from the same locations and read from the same things.. and it will work?

TS: Yes. I'm aiming at an exact pin-for-pin copy really so they should have the same pins going into their DMA that I've got going into mine (unintelligible here) .. whether I use them all. I don't think I will. I'm hoping to cut down on the number of pins that their using as well, thus making it a bit of a cheaper device.. gate array implementation. I'm designing and talking to them on the basis that when I've finished they can just plonk it on to the system that they've got and it will work first time or without extensive software modifications, because they are actually writing a big microcode for this system - 78 bit words - things like that, so it would be out of the question for them to change their software. The changes they would be prepared to do would be like I said - kicking the DMA, they could cut that out and be much happier doing that. Another thing they said they would be happy with was again using a memory management unit. They are really simplifications they hope that they will save some space on their software without extensive rewrites.

DS: Well when you do come to actually thinking about filling the blocks in, do write the ideas down as they come.

LB: I'm sure that you will be doing some kind of work over the holidays and putting some thought into it, so do keep the log going.

TS: I didn't realise at this stage where you are actually talking to people - like I'm talking to Company C----- - I didn't realise that this was going to take so much time of the project. I thought I had enough information when I understood how the system worked, without any thought to the rest of the system. I thought that I could just get on and do it, whereas Mr J----- in the first few weeks came along and said, "Right what happens there", and I hadn't thought about the rest of the system. So at this stage it's become more important than I really thought it would be.

A.3. DESIGN BEHAVIOUR GRAPHS

The diary and interview data of four of the original seven undergraduate subjects were structured into Design Behaviour Graphs (DBGs). For these subjects (NB, TS, MM and AD) data were selected for encoding primarily from the diary protocols, with only minimal recourse being made to the interview transcripts which tended to be of a much more retrospective nature. The DBGs for each of the four subjects are presented in the continuing sections of this appendix.

A.3.1. NB'S DESIGN BEHAVIOUR GRAPH

1 Design and implement an automatic tape position controller for a reel to reel tape machine

{LONG-TERM GOAL: ONGOING PURSUAL}

This inferred goal may be thought of as a basic statement of S3's ongoing aims. Within his 'Project Specification' S3 defines the desired functional requirements of the device, and additionally partitions the design into seven basic high-level modules: (1) A tape motion sensor (2) A microprocessor and memory devices (3) A keyboard for entering information and commands (4) A display (5) Interfacing for outputs and inputs (6) An auxiliary switching interface, and (7) A power supply unit. It should be noted that S3 provides a RATIONALE for his decision to include a microprocessor as part of the device. He states that the microprocessor "is necessary to allow some of the more complex functions, and it should also reduce the cost and complexity of the circuit." A block diagram characterisation of the above modules and their interconnections is provided within S3's Project Specification. The subject's initial pre-diary design work thus seems to have been carried out in accordance with the following three goals.

1.1 Define functional requirements of device

{GOAL 1.1 PURSUED AND ATTAINED}

1.2 Define high-level modules of device

{GOAL 1.2 PURSUED AND ATTAINED}

1.3 Devise representation of modules and interconnections in block diagram form

{GOAL 1.3 PURSUED AND ATTAINED}

1.4 Design tape motion sensor

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

★ *KAG-1* Investigate ways of measuring tape movement

{goal pursued}

"+++ some preliminary investigation was carried out and it became clear that the device relied on being able to measure tape movement; methods of doing so were looked at in some depth +++"

DECISION "+++ the conclusion was that some mechanical contraption was needed."
"I came up with .. [the idea of having] just an idler-wheel and the tape turns the idler-wheel as it goes past, and the wheel actually sends pulses to the.." [Interview 4/11/86]

RATIONALE "That's the way it's done commercially .. although I did actually weigh up all the different types and sort of methods I could think of to do it, first." [Interview 4/11/86]

1.4.1 Design mechanical aspects of tape motion sensor

{GOAL PURSUED}

CONSTRAINT "Due to the lead time on having such an object manufactured in the department it was necessary to design it as soon as possible if it was to be ready in time to use it."
"I knew that was going to be one of the key areas that was going to take time, because it's not in my hands; I have to give the plans to the technician and he goes away and does it +++" [Interview 4/11/86]

COMMENT "My supervisor said it was worth getting it out of the way .. and so I designed it +++" [Interview 4/11/86]

When S3 is retrospecting on the design of the tape motion sensor mechanism he comments that "decisions had to be made at a time when other details of the project were not clear, and to some extent this dictated the nature of the counting part of the device". It becomes clear later on that he is referring here to electronic aspects of the tape motion sensor (see comments associated with GOAL 1.4.2)

{GOAL 1.4.1 ATTAINED}

1.5 Implement mechanical aspects of tape motion sensor

{GOAL PURSUED}

Having arrived at a suitable design for the tape motion sensor mechanism, S3 passes this design on to the technicians for construction. It is built before the Summer vacation, and S3 takes it home to test out on his reel to reel tape machine.

DIFFICULTY "+++ well I had to bring it back because it was useless +++ it's not really up to the job +++ it's a re-build really. Once the sensor is made it will be very simple to use, all I've got to do is bolt it on and that's virtually it. +++ I would have probably thrashed the tape-motion sensor out 'til the end, but I can't because it's in someone elses hands.. so I've had to put that on one side.." [Interview 4/11/86]

COMMENTS "So at the moment I'm just working on other things - trying to get this block diagram into something that can be implemented using electronic components." [Interview 4/11/86]
"the remaining [design] work is to do with evaluating and choosing methods for turning the block diagram into a circuit diagram using available circuit components, and writing software to carry out the functions required by the specification"

From the immediately preceeding COMMENTS the following two goals (GOAL 1.6 and GOAL 1.7) are discernible

1.6 "[Try] to get this block diagram into something that can be implemented using electronic components"

{LONG-TERM GOAL: ONGOING PURSUAL}

It should be noted that this high-level goal emphasises the 'electronic' aspects of the remaining design work now that the 'mechanical' part of the tape motion sensor has been designed.

1.7 "[Write] software to carry out functions required by the specification"

{FUTURE GOAL: IMMEDIATE PURSUAL NOT INTENDED}

This is a long-term goal which appears to be mentioned by the subject as something that will need to be done at a future date. Clearly he has no intention of pursuing it for the time being.

1.4.2 Design electronic aspects of the tape motion sensor

{GOAL PURSUED}

It should be noted that this goal could also be labelled as GOAL 1.6.1 since it is a sub-goal of GOAL 1.6

ELABORATION (of goal) "+++ design a pair of light-gates using low cost infra-red LEDs and phototransistors (the choice of which was already made when designing the [mechanical aspects of the] tape motion sensor)"

CONSTRAINTS "+++ design a pair of light-gates +++ to give an output which could be used effectively by the rest of the circuit."

"The device will be at some distance from the rest of the circuit - it is necessary for it to have noise immunity; minimal current desirable."

DECISION & RATIONALE "Current requirements are small, therefore a 5V supply rail will not loose much potential through a long cable. CMOS at higher voltage would give better noise immunity (speed is irrelevant) but rest of circuit is likely to be at TTL levels, and voltage conversion is undisirable."

METHOD USED "Basic circuit theory was used to design the circuit around the optical devices (biasing required, and transistor load resistor to give large enough differences between light and dark current)."

{GOAL 1.4.2 ATTAINED}

1.6.2 Select display

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

☆ *OEG-1* "Evaluate different displays, all of the Intelligent LCD dot matrix type, offering similar performance."

{goal pursued}

CONSTRAINT "To find which display could do the most for a reasonable cost (not necessarily the lowest cost)."

PLANNED METHOD "Consideration of available data."

DIFFICULTIES "Data sheets were not available for all the devices; also data sheets are complicated and do not allow for a simple overview of these +++ More data sheets are required to evaluate components."

1.6.3 Design keyboard.

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.6.3.1 Design keyboard layout.

{GOAL PURSUED}
CONSTRAINT "To minimise the number of keys used while preserving the ease of use and ergonomic quality of having a separate key for each function."

IDEA "[Maybe] include a shift function in order to reduce the number of keys required."

METHOD USED "Designed keyboard layout and then attempted to work out whether it was suitable for the required functions."

DIFFICULTY "Designing a layout first and evaluating it was found to be unsuccessful +++"

DECISIONS "Keyboard functions must be defined in order to decide on keystroke sequences, only then may keyboard layout be decided.

"Keyboard functions need to be defined and an investigation of their software implementation made keyboard layout will be decided when this has been done."

QUESTION "Are these operations possible to implement in software?"

{PROGRESS ON GOAL 1.6.3.1}
PLANNED METHOD "+++ define the keyboard functions required for the device and understand the relationships between them. +++ represent each function as a series of sub-functions, in order to gain a minimal sub-function set capable of performing functions in combination. +++ use sub-function set as the basis for key functions, and design a keyboard to incorporate all the key functions."

METHOD USED
"(1) Wrote down definite (easily defined) key functions.
(2) Attempted to group functions in different ways: a) real time/interactive vs. non real time functions, b) hierarchical position in keystroke sequence.
(3) Attempted to construct a form of 'state diagram', but this does not lend itself to path branching and merging.
(4) Attempted to define functional/keystroke sequence flow diagram.
(5) Re-drew flow diagram each time problem was encountered.
(6) Noted that flow diagram suggested key hierarchy.
(7) Designed keyboard based on suggested hierarchy this resulted in a 22 key keyboard. Closest encoder is for 20 keys.
(8) Re-grouped primary and shift functions, and arrived at a final design concept."

DECISIONS
"Shift functions would be used to reduce the number of keys.
Numeric keys and Tape Drive Control Keys to be primary key functions.
Multiple shift fuhctions would be avoided if possible.
Keys should be grouped by function where possible or desirable.
Data or program entry sequences would be terminated using an ENTER key, to make keyboard action positive."

1.6.4 Choose microprocessor and design support devices for microprocessor.

{GOAL PURSUED}

1.6.4.1 Choose microprocessor

{GOAL PURSUED}
"Although a formal study of microprocessors has not been undertaken, some research has been done which suggests the R6511Q is the optimum choice. A 99% certainty exists of this being the microprocessor to be used, and this has so far dictated certain power supply requirements and the crystal frequency."

COMMENT "I was recommended it [i.e. the microprocessor] actually by someone else" [Interview 4/11/86]

{GOAL 1.6.4.1 ATTAINED}

1.6.4.2 Select clock crystal

{GOAL PURSUED}
CONSTRAINTS "To select a crystal of minimal size and cost which would do the job required of it."
"Crystal required to have a resonant frequency of 2mHz."

The crystal frequency was dictated by the choice of microprocessor.

COMMENT (on design alternatives)
"STC components had a choice of two suitable crystals; it was not necessary to look further."

See GENERAL CONSTRAINT & GENERAL METHOD below which bears on this prior COMMENT

DECISION & RATIONALE "Two suitable crystals appeared to be those under consideration; the smaller and cheaper one was chosen (accuracy not essential)."

{GOAL 1.6.4.2 ATTAINED}

GENERAL CONSTRAINT & GENERAL METHOD "Project budget is a general constraint +++ The polytechnic has an arrangement which allows STC components to be substantially cheaper than most other suppliers. STC is therefore the first stockist to be considered +++".

1.6.4.3 "Design a circuit to hold the microprocessor RESET pin low for a nominal period on 'power up' to make operation predictable."

{GOAL PURSUED}
CONSTRAINTS "The RESET pin must be held low for at least 20ms on power up, and should also return low in case of momentary supply voltage change, to prevent data corruption or spurious operation."

DECISION "A simple RC network providing the input to a buffer, with T = 20ms, would be sufficient."

RATIONALE "Having come across this standard circuit for implementing this function many times before, it was difficult to see any better way to achieve the desired end."

{GOAL 1.6.4.3 ATTAINED}

1.6.3.2 Design keyboard circuitry.

{GOAL PURSUED}
DECISION "+++ use a keyboard encoder, but allow some keys to interrupt the processor when it is not polling the keyboard."

DIFFICULTY "The 74C923 is the only 20 key encoder available +++ [this] would handle everything but interrupts - these could be decided on later when designing software." <DEFERRED DECISION>

1.6.3.2.1 Select capacitors for keyboard circuit.

{GOAL PURSUED}
METHOD USED "+++ simple guesses at scan frequency and debounce period were made to allow capacitors to be selected."

{GOAL 1.6.3.2.1 ATTAINED}

COMMENT (on general activities) "In general turning block diagrams into electronic components."

1.6.5 Design tape drive interface circuit for reel to reel and cassette machines

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.6.5.1 Design interface circuit for reel to reel machine

{GOAL PURSUED}

CONSTRAINTS "To design a circuit to interface 5v logic levels in the circuit to those required by the reel to reel machine - 24v pulses at the remote control socket."

"To impose the minimum load on the PSU of the tape machine, which is not designed to source much power."

COMMENT "A circuit design was arrived at by degrees"

> In his Diary for this week S3 provides a series of circuit diagrams to show the sequential design of the tape drive logic, and a brief account is given of relevant decisions (e.g. inclusion of a potential divider) and the rationales behind them. A rendition of this detailed design work is not included here.

{GOAL 1.6.5.1 ATTAINED}

1.6.5.2 "[Aim] To simplify the design, and hence the construction +++ of [reel to reel] tape drive logic"

{GOAL PURSUED}

"+++ investigate the feasibility of using buffers with open collection outputs to simplify the tape interface - i.e. a particular type of buffer was under consideration."

> It appears, then, that S3 is not satisfied with the design of the reel to reel tape drive interface that was attained last week

METHOD USED "The circuit diagram was modified to include open collector buffers and simple calculations were done to check that the circuit would work."

DECISION "1 open collector buffer chip could replace half the transistors and half the resistors in the original design; this would be done."

{GOAL 1.6.5.2 ATTAINED}

> S3 has thus "arrived at a suitable design to switch the 24v pulses to the reel to reel remote control socket." This circuit, however, is only a section of the whole tape drive interface that needs to be designed. From his Diary it can be discerned that he still has to (i) design the cassette remote control switching circuit and (ii) design the related circuitry to drive a set of LED indicators since he has previously made the DECISION that LEDs should be provided to indicate which tape drive functions are currently instantiated by the user. A major CONSTRAINT that is mentioned is that all the signals which control the tape machines are derived from a single 8 bit I/O port. There is therefore the need to (iii) include circuitry to ensure the appropriate routing of control signals. It is clear from the Diary that S3 conceptualises these three goals as being inextricably interconnected, which indeed they are - particularly by virtue of the aforementioned CONSTRAINT. S3 therefore elaborated goal 1.6.5 as a more detailed specification of what he was attempting to do (see below).

{GOAL 1.6.5 ELABORATED}
"To design a circuit which would handle the remote control signals for reel to reel and cassette machines, and keyboard switch indicators (LEDs) to indicate certain functions, all from a single I/O port."

{GOAL PURSUED}

This goal may be viewed as a more detailed restatement of GOAL 1.6.5 - bearing in mind that it has been partially fulfilled by the progress that has been made on the design of the reel to reel tape drive logic (GOAL 1.6.5.2). S3's account of his design work in pursuing GOAL 1.6.5 is in the form of a fairly retrospective summary of design decisions and the reasoning behind them (see below).

<u>*CONSTRAINTS*</u> "Certain signals require a pulse only (Play, Stop etc), some need to be held on (Pause, reel to reel) and combinations of some signals required (Play and Record)."

<u>*DECISIONS & RATIONALES*</u> "It was decided that, for simplicity, the LEDs could be driven directly from TTL buffers since they employ internal current limiting and thus no drivers or resistors would be required. It had also become clear that open collector buffers would be needed to switch the reel to reel remote control. Investigation of the cassette machine remote input showed that it required the input of a high or low signal on each line to provide -two- functions and in order to make the line inactive it would be necessary to leave the line floating. This naturally indicated the need for tristate buffers. Thus each section of the interface required a different type of buffer device. It was initially thought that the buffers could be driven from decoders, such as four line to sixteen line decoders, but it soon became clear that this would not allow sufficient flexibility to produce both 'Play' and 'Record' signals and similar multiple functions. Also the PAUSE signal and all the LED indicators would require constant assertion of a level, whereas other functions would only require momentary pulses. A number of different circuits were laid out and a 'dry run' evaluation (what would happen if?) was done. Eventually it was felt that using latches would provide plenty of flexibility, and this solution simply requires a bus and select lines from the port. +++ [Thus] Three latches would handle each function (one each for reel to reel machine, cassette machine and LED indicators). Buffers would be required between each latch and its signals."

{GOAL 1.6.5 ATTAINED}

(1.6.4.4) "[Aim] To select ROM and RAM for the microprocessor."

{GOAL PURSUED}
<u>*CONSTRAINT*</u> " At 2mHz clock frequency, access time required is less than 500ns."

<u>*DECISION*</u> "No RAM required (external to the microprocessor); 2764 EPROM suitable."

<u>*METHODS USED*</u> "Catalogues were consulted to find the capacities and prices of ROM, and the one which had sufficient capacity at the lowest price was chosen. The requirement for RAM was assessed, and it was found that the microprocessor has enough built in RAM to fulfill this requirement."

{GOAL 1.6.4.4 ATTAINED}

1.6.6 Design status signal interface.

{GOAL PURSUED}
ELABORATION (of goal) "To design a circuit to buffer external signals from the tape machines and connect them to the right logic levels for the microprocessor."

CONSTRAINTS "Voltage levels need to be changed to microprocessor logic levels."

DECISIONS "Using a tristate buffer and potential dividers, the interface could be connected to the same port as the keyboard interface."

{GOAL 1.6.6 ATTAINED}

{PROGRESS ON GOAL 1.6.3.1}
CONSTRAINTS
"To lay out the keyboard in a way which makes it easy to use and logical so that it is easy to get used to."
"The keyboard should be laid out in a logical manner with keys where they would be expected to be found."

DECISIONS
"All the keys duplicating the normal functions of the reel to reel machine's remote control device were grouped together.
The group of tape drive functions was placed in the same order as they appear in on the machine and the remote control device.
The numeric keys were grouped together.
The relationship of the numeric keys to one another was decided on as being the same as that used in most numeric keypads (e.g. on calculator keyboards) to make it familiar.
Of the functions remaining, the functions which needed to be the first function used in a key sequence were given unshifted main functions; the others were nominally assigned shifted key positions but these depend on the software and may be altered later.
The non-tape drive and non numeric functions were grouped together.
The tape drive functions were placed under the imagined display position.
The numeric keys were placed to the right of this (secondary importance) so that right handed users would not need to reach across the display.
The remaining function keys were placed under the imagined display positions between the display and the tape drive function keys i.e. further away from the operator because less used than the tape drive functions."

METHOD USED (to reach final design of keyboard layout) "Having observed the 'rules' [i.e. the above DECISIONS], several possible layouts were drawn out and they were evaluated by doing some dummy' keystrokes."

{GOAL 1.6.3.1 ATTAINED}

1.8 Implement circuit designs as hardware

{LONG-TERM GOAL: ONGOING PURSUAL}

1.8.1 Implement keyboard circuit as printed circuit board

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.8.1.1 "[Aim] To produce a printed circuit board design which would be easy to implement and would simplify construction"

{GOAL PURSUED}
DECISIONS & RATIONALES
The encoder IC should be on the circuit board so that the unit is self contained and may be tested as an entity.
A suitable plug/socket should be provided on the board to make connection to the rest of the circuitry straightforward.
All connections to components should be on the underside of the board to make connecting the components easy.
+++ Because the keyboard circuit is basically a matrix, i.e. a square grid, it makes sense to make a double sided board and have all lines running top to bottom on one side and all lines running left to right on the other.

{GOAL 1.8.1.1 ATTAINED}

1.8.1.2 Manufacture transparencies of keyboard printed circuit board design

{GOAL PURSUED}
METHOD USED
"Most of the soldering points were marked in their relative positions (particularly because this was a keyboard) and, reading directly from the circuit diagram, most of the lines that could be horizontal were drawn in. When this had been adjusted, lines crossing them were added to the other side, and alterations made until a satisfactory solution was found."

{GOAL 1.8.1.2 ATTAINED}

1.8.1.3 Drill [keyboard] printed circuit board

{GOAL PURSUED}
"+++ printed circuit board was made up during the week and had to be drilled +++"

{GOAL 1.8.1.3 ATTAINED}

1.8.2 Implement remaining circuitry (separate to keyboard circuit) as printed circuit board

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.8.2.1 "[Aim] To design a printed circuit board [separate to keyboard printed circuit board] on which all the components of the project could be assembled but be hard wired together i.e. to construct a purpose built prototyping board."

{GOAL PURSUED}
DECISIONS & RATIONALES
"The board should accept all the components envisaged for the project and have some space for additional components.
The layout should attempt to make interconnecting wires easy to add to the board.
The layout should be based on component characteristics (i.e. pinouts) and the necessary positioning to make components as easy to interconnect as possible.
Power supply rails should be laid down and where many connections are to be made to a point (e.g. IC pad) two pads should be provided to give more room to make connections.
Extra pads should be placed for passive components (e.g. pull up/down resistors and decoupling capacitors.

METHOD USED "The processor was seen as the central component and other components were placed according to the processor pinout. Also, spaces for sockets for inter-board and tape machine and display connections were provided. The socket for connecting the keyboard was placed at the lower edge, such that the keyboard would be nearest the operator when it was connected.

{GOAL 1.8.2.1 ATTAINED}

1.8.1.4 "+++ add all the components to the [keyboard] circuit board"

{GOAL PURSUED}

METHOD USED "Conventional construction techniques were used."

1.8.2.2 "[Aim] To drill the second [prototyping] printed circuit board and cut it to size, and add components if time allowed."

{GOAL NOT IMMEDIATELY PURSUED}

It should be noted here that the Christmas vacation begins at the end of this week and the project lab will then be inaccessible to the subject. This point relates to the CONSTRAINT mentioned below.

CONSTRAINT "It would be desirable to have drilled the board since this would then allow construction to proceed outside the project lab, i.e. during the Christmas period if time allowed."

DECISION & RATIONALE "All the holes on the board would be drilled since they may all be needed and having drilled them it may add to the versatility of the board."

{PROGRESS ON GOAL 1.8.1.4}

* *TSG-1* "[Aim] To complete the construction of the first printed circuit board [for keyboard] so that it could be tested and any modifications necessary could be planned."

CONSTRAINTS "Task 1 [i.e. GOAL 1.8.2.2 - drilling and cutting of second PCB] should be done first since it has a higher priority/the need for it is greater."

{PROGRESS ON GOAL 1.8.2.2}

METHOD USED "PCB drilling machine used - hole sizes depend upon the size of the leads/pins to go through them."

COMMENT (on planned implementation of circuit on prototyping board) "The second circuit board is a 'development' board, and so the interconnections will be added by hard wiring once the devices have been set in place. Extra spaces have been provided in case more devices are needed, and the decision to be made was whether to drill the holes for them or not. It was decided that the holes would be drilled, otherwise the task of drilling them once construction had started would be too difficult, and time would not be wasted by doing it at this stage.
Also it is not anticipated that some of the pads will need holes in them, once wires are to be soldered to them and no component leads need to pass through the board to them; however, drilling holes will not take very long and may be useful later."

{PROGRESS ON GOAL 1.8.1.4}

DIFFICULTY "The response time of the keyboard is too slow +++"

DECISION "+++ change the keybounce mask capacitor by a factor of 10 to 1mF (from 10 mF)."

RATIONALE "+++ 1mF was an 'educated guess' helped by a graph in the data sheets, and turned out to be suitable."

DIFFICULTY "The keycaps ordered are of the wrong type +++ on attempting to fit the keycaps, they were found to prevent the keys from moving."

DECISION "+++ re-order [keycaps]."

{PROGRESS ON GOALS 1.8.1.4 AND 1.8.2.2}

"By the end of the last project session of the autumn term, the progress was as follows:
All components except LEDs and keycaps fitted to keyboard, including corrected value of capacitor for keyboard response; keyboard encoding circuit found to be functioning correctly.
Ribbon cable between keyboard and main board made up.
Plugs for keyboard and display added to main board , also all the sockets thought to be needed (all holes drilled).
14 way plug for attaching display made up on the cable (combination of 10 way and 4 way plugs), also pins attached to display and socket attached to other end of ribbon cable."

{GOAL 1.8.2.2 ATTAINED}

1.8.2.3 "Wire as much of the circuitry [on main pcb] as time allowed"

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

S3 pursues GOAL 1.8.2.3 over the vacation period, attempting to do as much wiring "as time allowed". Not only is he aiming to do this wiring but he also wants to then test the circuitry on both pcbs (GOALS 1.8.3) and if faults are found to trace these (GOALS 1.8.4) and rewire/redesign the circuits appropriately (GOALS 1.8.5). A retrospective account of this vacation work is provided in his Diary and is included below, The subject makes few statements concerning the goals that were directing his behaviour, and little attempt has been made in the DBG to elucidate the goal structure of this detailed work. It is important to realise, however, that the subject's activities relating to construction, testing, fault finding, rewiring/redesigning, retesting etc become increasingly intertwined at this point in his project and show a clear cyclic and iterative structure. From S3's account it is clear that he tended to construct a small section of the circuit and then test (and if necessary redesign) this section rather than waiting until he had constructed a much larger section before proving its operation. The cyclic and iterative nature of these activities becomes discernible when reading the combined PROGRESS sections relating to the aforementioned GOALS.

{PROGRESS ON GOAL 1.8.1.4}
"Added LED status indicators to keyboard."

{GOAL 1.8.1.4 ATTAINED}

1.8.3 "To test as much of the circuitry [on both pcbs] as time and equipment allowed"

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.8.4 "To trace faults in circuitry and +++"

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.8.5 "rewire/redesign circuits until they were made to work."

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

A.3.2. TS'S DESIGN BEHAVIOUR GRAPH

1 Redesign an existing application specific Direct Memory Accessing unit to overcome current performance deficiencies

{LONG-TERM GOAL: ONGOING PURSUAL}

This inferred GOAL may be thought of as a basic statement of S3's ongoing aims. The existing Direct Memory Accessing (DMA) unit - implemented in discrete logic as board level components - is an integral part of a CAD graphics workstation being developed by Company C-----. The existing DMA unit which the company are working with, while seemingly usable, appears to be far from optimal from a software management point of view; as S3 puts it "'Software' are complaining because they are having difficulty - timing problems and things like that..'". S3 has therefore been asked to attempt a redesign of the existing device to improve its performance (see below).

CONSTRAINTS "So what they've asked me to do is to modify it and make it quicker, easier to use, and perhaps make it cheaper +++" [Interview 4/11/86]

DECISION & RATIONALE "A TTL logic design has already been implemented to do this [to function as a DMA system] but the advantages of improved speed, versatility, reduced component size, cost, [and] power requirement suggest that a gate array implementation would be beneficial to the overall system." [Lab book, p.1]

S8 makes a DECISION to use the Apollo CAD system in the Polytechnic for the gate array redesign of the DMA unit. The RATIONALE for using this system - which may be discerned from the S8's comments - relate to the facts that (1) the system is readily accessible (2) some basic familiarity with the system has already been gained and (3) S8's supervisor has extensive experience of gate array design work on the Apollos.

{PROGRESS ON GOAL 1}

PLANNED METHOD (for tackling design) "What I've decided to do is to break the project into two. Firstly, to meet the initial ... the exact specifications of the DMA controller +++ and then [secondly] going onto the side of research and looking at the rest of the system - that will be the Mark 2 version, totally separate. +++ I think it's a bit of an ongoing project. That's really why I've split it into two. +++ I can incorporate a small amount of control logic for one area - just the graphics processor - and no doubt more areas will come up which I think 'well perhaps I could put that that in as well'" [Interview 4/11/86]

The suggestion to thoroughly investigate the control aspects of the DMA unit and the idea of incorporating additional control logic into the unit appear to come from S8's supervisor [Mr J-----] : "What Mr J----- wants me to do is look at how they control this DMA unit and try and incorporate some of the logic from other areas of the system and put it onto the [DMA] controller. [Interview 4/11/86] " Moreover S8 doesn't think that the company will be interested in this side of the project: "+++ they haven't suggested that I carry on and look at the rest of the system and do control, and I don't think they'd be all that interested if I did +++" [Interview 4/11/86]

CONSTRAINTS "So what I'm trying to inflict is: keep [DMA Chip] Number 1 cheap, simple and small, and [DMA Chip] Number 2 [ie Mark 2 version] - keep that as small and simple as possible as well, and keep it so that it is totally testable +++ there's no point building something and missing out all the test circuitry +++ that would mean that the thing, if unreliable, couldn't be tested - they wouldn't be able to find out what was wrong - so I can't take short cuts to make it cheaper +++ As I draw in other areas of control +++ I'm going to be taking more and more signals from other areas of the system - the way that affects my project is that it puts more pins on the end device and makes it more expensive. What I'm trying to do is keep it cheap.." [Interview 4/11/86]

★ *KAG-1* Gain knowledge of DMA unit functionality

{goal pursued}

★ *KAG-1.1* Investigate commercially produced devices

{goal pursued}
"There are a lot of DMA controllers on the market, but the special thing about this one is that it is 32 bit which is bigger than the normal device. So what I've done is looked at the usual 16 bit devices and seen what facilities they offer...there are things like chaining blocks of data +++" [Interview 4/11/86]

{goal attained}

★ *KAG-1.2* Look at diagrams for previous board

{goal pursued}
"I've looked at their board and seen how they've done different things - why they've put certain logic blocks in and so on +++" [Interview 4/11/86]

{goal attained}

★ *KAG-2* "I aim to expand my existing understanding of the DMA unit operation and to understand how the 'system' controls the DMA unit"

{goal pursued}

RATIONALE " +++ I don't understand how the rest of the 'system' tells the DMA what to do. This has lead to questions of how the unit is controlled and can I expand my design to include some of the control circuitry, hence make the end product more adaptable to alternative uses."

★ *KAG-2.1* "Write to Company C----- for further information"

{goal pursued}

"I am writing my questions down and posting them, as well as telephoning and asking questions. +++ I am telling Company C----- how I believe the system works, and raising questions. That way they can tell me if my understanding is at fault, or give me information to complete the story."

★ *KAG-2.2* "Write down how I think the system works"

{goal pursued}

A Lab. book entry of 15/10/86 entitled 'My understanding of how the Company C----- DMA controller works' shows that S8 had already begun to tackle this goal. On the 4/11/86 his Lab. book contains a 'Review of cct. operation' which is an extensive description of how he believes the graphics system operates, including details of the role of the DMA unit and the means by which it is controlled. Many questions are raised by S8 in both of these Lab. book entries. Some of the content of these Lab book entries is repeated by S8 in the 'Introduction' section of his project write-up.

☆ *OEG-1* "Evaluate what parts of the overall system could be included in the project"

{goal pursued}

This is really an ongoing goal that is pursued throughout the course of the project, though mostly S8 provides no explication of the evaluation process engaged in.

● *PDG-1* Write project report

{intermediate term goal: ongoing pursual}

● *PDG-1.1* "At this stage a project Introduction could be written to clarify my project objectives with all interested parties"

{goal not immediately pursued}

1.1 Draw a block diagram with connections that may be necessary

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}
RATIONALE (for doing block diagram) "+++ so that I can deal with modules of the project rather than trying to do the project as a whole +++ later I can elaborate on each module as I am ready or information is available."

S8's non familiarity with the CAD system seems to lead him to the decision to do the detailed block diagrams on paper and simple diagrams on the CAD System.

1.1.1 "Get detailed [functional] diagrams on paper"

{GOAL PURSUED}
For project Number 1, which is a direct copy, I have +++ got a functional block [on paper] because there are only three blocks in it - so that was fairly easy +++" [Interview 4/11/86]

COMMENT (on functional decomposition) "the [DMA] unit can be broken down into 3 distinct areas: IOPORT - Transfers data - copes with speed difference; ADDCOUNT - Acts as address pointer; CONTROL - Allows the user to control what happens when. Labels defined from previous circuit (TTL)." [Lab book p.1]

1.1.2 "Do simple functional diagrams on CAD system"

{GOAL PURSUED}
PROBLEM "Non familiarity with commands on the CAD system means that I am having difficulty setting up 'files' on the system."

★ *KAG-3* Gain familiarity with CAD system "which will be used for all my design circuit work and simulation"

{goal pursued}
"I am actually familiarising myself with the system at the moment." [Interview 4/11/86]

COMMENT (relates to KAG-2.1) "I am waiting for some information from the company who initiated my project, regarding how the system deals with specific problems, ie start-up, and updating information. +++ The data is not particularly vital since I have been able to work on other areas of my project, so I haven't tried to phone or speed up the data."

{PDG-1.1 repeated & elaborated}
"Aim to get a full introduction to my project, with regard to how it [the DMA] fits into the rest of the 'graphics system' and an explanation of how it works and is controlled +++"

* *{goal pursued}*
TSG-1 "+++ [this] must be done as soon as possible for the company who have an interest"

DECISION "Decided to work solely on the introductory chapter, and not do practical work until this important section has been done."

{progress on PDG-1.1}
"I have written a basic 'system' explanation, explaining where my DMA control unit fits into the system."

PROBLEM "It takes a long time to put my explanations into the word processor and get the desired result."

COMMENT "I don't feel that I'm getting on with the project, and time is passing by too quickly. I feel that I must get this chapter out of the way before I can get fully underway with the practical side of the project."

● *PDG-1.2* "Intend to write report on DMA unit with more technical detail and state the aims of the project"

{goal not immediately pursued}

{Progress on PDG 1.1}
"Completion of project introduction written using a word processor."

{PROGRESS ON GOAL 1.1.2}
"Block diagram of DMA unit started using Apollo CAD system - have drawn one block."

✱ *TSG-2* "Aim to get [the high level] block diagram completed [on the CAD system] next week +++ - A milestone for the project on the CAD system"

GENERAL CONSTRAINT "I am not able to spend as much time on my project as I would like due to other work which is necessary. +++ I feel I am still at the beginning - hardly started."

GENERAL PROBLEM "The CAD software is about to change so detailed [low level] circuit diagrams cannot be designed."

{PDG-1.2 repeated}
"I have decided that my project report will require a detailed analysis of how the graphics system works and controls the DMA."

{goal pursued}

{PROGRESS ON GOAL 1.1.2}
"Drawn two library cells on the CAD system. These are basic functional blocks for the system, which are high level blocks in the hierarchical design process."

PROBLEM "Problems with wiring buses due to special component definitions required by the CAD system."

★ *KAG-4* "Read Apollo CAD system handbook for wiring the block diagrams together, to overcome wiring buses problem which I have encountered"

{goal pursued & attained}

✱ *{TSG-2 revised}*
"[I aim] to complete the [high level] functional block circuits of the DMA unit so at Christmas I can take a block diagram to Company C----- and show them my intentions for the design"

GENERAL PROBLEM "I cannot make the functional blocks explicit to the component level because the updated library which I must use hasn't arrived at the Polytechnic yet."
"+++ the CLA 5000 - which is the gate-array system that we're using - has got a new library out which we haven't got yet, so I haven't been able to go into the blocks and put components in +++" [Interview 9/12/86]
"+++ because the library hasn't been there, there hasn't been much point in doing it [detailed design with the Apollos]. It was supposed to be here in October. +++ I could [use the existing library] as far as working out speed of components, but when the new one turned up I would have to redefine all my blocks +++ it's fairly simple stuff inside the functional blocks so there's no point going ahead and doing those and having to repeat the process later on - when we're [S8 & P] fairly confident it's going to work anyway." [Interview 9/12/86]

DECISION "Think about internal components for blocks so that when the library that I need appears I can use it."

{PROGRESS ON GOAL 1.1.2}
"Having defined my functional blocks I have now linked them together with the wires that I expect to use in the system - All CAD system work."

PROBLEM "Due to a lack of information from C, a few questions, and alternative design paths have arisen which need sorting out."

S8 gives specific details of these 'alternative design paths' in his Diary entries for Week 7 and in the Interview of 9/12/86.

DECISION "I shall design how I think best, but keep my options open."

★ *KAG-5* "Will go and talk to Company C----- [about design alternatives] during the Christmas vacation"

{goal not immediately pursued}

COMMENTS (on planned gate array design work) "When my functional block diagram is complete and agreed with Company C----- it should be a 'simple' process to complete all the circuit design within these functional blocks, since there will be no ambiguity on how the system should function"
"Inside the [blocks of] the DMA - I haven't given it much thought. +++ The thing is, within the blocks its fairly simple standard stuff: like the I/O port is just a register, it's just D-types, which are on the gate-array system ... there's blocks, units ... Similarly the counter, that's just a set of latches. So because I've designed those things before, I'm just confident enough to have not thought about them much at the moment."
[Interview 9/12/86]

GENERAL COMMENT "I didn't realise that the system analysis would be such a large part of the project, and I have now decided that it will probably present the most difficult stage of the project due to the interaction with Company C----- and deciding on the best methods for achieving the best end result."

{progress on PDG-1.2}
"Writing down and defining how the graphics system will work, has been my main area of progress this week."
"I have mainly been studying my original notes on how the graphics system works, and expanding the detail in some key areas, such as the layout of the Physical System Memory, as regard to memory mapping."

{KAG-5 repeated and elaborated} "+++ I am going to have to discuss with them [C] exactly what they need, to decide which design options to take for my final block diagram. Two main methods have been identified with concern to 'ADDRESSING' +++"

{goal not immediately pursued}

ELABORATION (on design options for addressing) "+++ The graphics processor seems to be the only 'master' with respect to loading the address counter of the DMA unit, and so the address data need not be read through the I/O ports, thus giving a faster loading time."
"If I load the address counter through the I/O ports, the address could be loaded from either the graphics processor or the system processor - but why might this be done?"

ELABORATION (on design options for addressing) "So I have now got a functional block diagram +++ actually on the CAD system which is wired together. +++ alternative design ideas have come up with regard to placing of functional blocks - such as ... its got an I/O port and an address counter and a bit of control logic that controls the two systems ... now as far as I understand the address counter can be loaded from - is only loaded from - the graphics processor. So in my block diagram design I can put it in one of two places: either load it directly or through the I/O port ... so that is a question that has come up with the design. +++ That was one of the questions I asked them - 'How do they load the address counter and why - which I haven't found out +++ I need the functional specification in more detail +++" [Interview 9/12/86]

DECISION "+++ so what I've done is done two block diagrams: one with loading the address counter through the I/O port and one with taking it directly off the graphics bus. So I've got two block diagrams now and I'm just going to have to take them up and see them next week." [Interview 9/12/86]

IDEA (concerning control) "I haven't started this second phase - which was the idea of more control - and that's because I need the information from Company C-----. Having said that, I've thought about it, because we [S8 & Mr J-----] came up with the idea that you need control status registers +++ That's really going to be phase two [BUT] I've sort of discovered that I have got to really keep to what they want and not expand my ideas too much as far as they are concerned ... I don't think they would be interested.." [Interview 9/12/86]

CONSTRAINTS "I am aiming [at least] for an exact pin for pin copy [of the DMA] +++ I'm [even] hoping to cut down on the number of pins that they're using +++ thus making it a bit of a cheaper device. +++ I'm designing and talking to them on the basis that when I've finished they can just plonk it on to the system that they've got and it will work first time or without extensive software modifications, because they are actually writing a big microcode for this system +++" [Interview 9/12/86]

IDEA (concerning buses) "An area that did appeal to me to start with was to expand the buses. Instead of having a 16 bit bus, take a bigger bus - a 32 bit bus. In that case they could use a different processor than the one they've got now - there are others available but they cost more." [Interview 9/12/86]

IDEA (concerning memory management system) "Then also go into memory management on board the chip and again that would speed everything up +++ if you had memory management, you could say 'Right, that's at that location in the big storage which is slow to access, and right, we can dump it over here but call it the same memory location and then everything can refer to the same memory locations. That makes things a lot more simple for the software people." [Interview 9/12/86]

1.2 "[I aim] to fill out the 'I/O port' and 'Addcount' blocks with gate-array logic components, and to make some initial designs of the control logic +++"

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

✱ *TSG-3* "Must have substantial circuit diagram and design by 5th Feb when external examiners will be looking at the projects"

1.2.1 Design I/O port circuit

{GOAL PURSUED}

★ KAG-6 Look at data books for designs of commercially available I/O ports

{goal pursued & attained}

PROBLEM "+++ design selection is [the] biggest problem."

DECISIONS "Looking at data books for I/O ports and their implementation has led to my design of I/O ports using latches and tri-state buffers."

> From now until Week 16, S8's work appears to be concentrated toward the design of the I/O port using these components and its subsequent verification. Unfortunately S8's Diary contains little reference to his design work on this module. It is possible, however, to discern the basic design stages of the I/O port from his circuit diagrams and retrospective project write-up. The I/O port is a 16 bit bidirectional data port and it is therefore necessary for S8 to design a 16 bit bidirectional register (GOAL 1.2.1.1: To design 16 bit bidirectional register). To this end, S8 pursues the design of a single bit bidirectional register or what he terms a CELL (thus attaining GOAL 1.2.1.1.1: Design CELL). During the design of the CELL relevant controlling signals are also defined (so attaining GOAL 1.2.1.1.2: Define control signals for CELL). S8 then connects 16 CELLS in parallel (thus attaining GOAL 1.2.1.1.3: Connect 16 CELLS in parallel) to produce the 'REGISTER'. The design of CELL - and thence REGISTER - appear to progress very swiftly and fairly smoothly, with circuit diagrams being first devised on paper (see Lab book) and then being implemented on the CAD system using the CLA-5000 gate array library. Later, to complete the design of this module, driving components are included to drive the 16 CELL components (so attaining GOAL 1.2.1.1.4: Add driving components to CELLS).

GENERAL COMMENT (on planned gate array design work) "I don't foresee any design problems. I am fairly confident on how counters work and how registers work so I am confident that I can get the design done." [Interview 9/12/86]

GENERAL COMMENT (on planned testing of design) "Testing is going to be a problem that I am going to come up against next +++ the test methods have got to be designed at the same time as I am designing the circuit. +++ I've given it a bit of thought in that it shouldn't be too difficult to test my I/O port or my counter +++ because they are just in one side from a bus and out the other side to a bus. So that's pretty straight forward ... just through information - when you put something in one end it should come out the same the other end." [Interview 9/12/86]

1.2.2 Design Address Pointer circuit

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

★ *KAG-7* Investigate designs of commercially available binary counters

{goal pursued}
"Counter is a basic binary counter, which again is designed by comparison with binary counter designs already implemented in commercial ICs."

> Although S8 certainly proceeds to research into possible designs for the Address Pointer (or, as he terms it, the 'ADDCOUNT' module), little description is provided of what is learned from this research or of how he plans to pursue his design. Similarly no observable manifestations of this research in the form of circuit diagram sketches for his ADDCOUNT are evident until many weeks later.

1.2.3 "+++ make some initial designs of the control logic"

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}
COMMENT (on design of control logic) "With the 'top level' block diagram completed I know what signals are comming into the DMA unit from the rest of the system, so I can design the control logic."

PROBLEM (with design of control logic) "Control logic definition is difficult since I am using signals that may well have been 'conditioned" for specific time delays and conditions earlier in the system design."

> Again, although S8 is certainly giving some thought to the design of the Control module, he isn't seen to be pursuing a tangible low-level circuit design.

GENERAL COMMENT (on planned testing of design) "Later I will need to consider testability of the blocks, although the I/O port and Addcount blocks will be easily tested since both their outputs and inputs will be accessible externally to the DMA chip, so can be tested without extensive test logic being built into the system."

GENERAL COMMENT "+++ care must be taken if there are any time-delay critical areas of the design."

1.2.1.1.5 Update design of CELL (and thereby REGISTER)

{GOAL PURSUED}
RATIONALE "update necessary since I used a CMOS component before, and the logic levels on the input are TTL, hence the system would not have worked."

COMMENT "New diagram for CELL and REGISTER."

{GOAL 1.2.1.5 ATTAINED}

{PROGRESS ON GOAL 1.2.2}
DECISIONS "Following recent correspondence with Company C----- I have decided to include a second address counter to allow two address locations to be stored. +++ Control Registers are another useful facility which I would like to include. These registers must be read from and be written to by both the system processor and the graphics processor. These will be implemented in exactly the same way as the I/O port since it is a register."

1.2.1.2 "+++ verify (prove through simulation) the I/O port"

{GOAL PURSUED}
"I shall complete the test routine for the verification today - this is just a simulation of the I/O port in operation."

1.2.1.2.1 Verify the operation of a single CELL

{GOAL PURSUED}
"[I have completed a] verification run ([see] timing diagram) of CELL.
[I have also made an:]
- Investigation into start up (see timing diagram). This was done for interest to see how long the system propagation delays were, and to calculate what time the CAD uses in its simulation. Typical time delays are used.
-Investigation into tri-state operation.
-Investigation into data direction reversal."

COMMENTS (on results of these investigations) "All information confirmed that the system uses typical propagation delay times for simulation. Also that there will be no problems due to propagation for the circuit under operating conditions of 10MHz data rate."

PROBLEMS "Problems with the design and verification of the I/O port have mainly arisen due to my unfamiliarity with the CAD system +++ There are a very extensive number of commands, and also some faults on the CAD system."

COMMENT "Through continual reference to the Apollo User's Guide and 'Idea' system reference manuals I am becoming familiar with what the system is capable of doing, and how to use the commands to achieve the desired effects."

{GOAL 1.2.1.2.1 ATTAINED}

{PROGRESS ON GOAL 1.2.2}
* *TSG-4* "I aim to spend less than 2 weeks designing the counter - and to prove it +++ Completion aim for counters - 24th February"

{progress on KAG-7}
"I am reading data books for information on commercially available counters for ideas on implementation of synchronous counters."

DECISION "The counter should be a tri-state device so I can have several counters, independent of each other on the system."

{KAG-7 attained}

{PROGRESS ON GOAL 1.2.3}

* TSG-5 "I aim to have broken the Control block into subsections and have definite plans for implementation shortly after having completed the counter (beginning of March, say)"

DECISION "I have decided that I will only make one design for the DMA unit - not 2 as originally hoped."

RATIONALE "This is due to the slow start in getting the CAD system fully under my command, and the relevant component library only appeared this January +++"

☆ *OEG-2* Evaluate commercial counter designs

{goal pursued}
"Evaluation of different circuit implementations for synchronous counters which are available as TTL logic components, eg 74193 binary counter."

{TSG-4 repeated}
"Aim to get the counter designed by next week - 24th February"

{PROGRESS ON GOAL 1.2.1.2}

PROBLEMS "[Attempted] verification of I/O port (as done last week for CELL unit), [but] problems in verifying the I/O port 'system' because I have organised my files in the Apollo system such that each unit can be run individually, but cannot be combined to run as a group on system [that is] although each individual unit could be tested, ie CELL, the total I/O port system couldn't be tested because it was ignorant of the workings of cell."

METHOD USED (to overcome problem) "I have reorganised my files within the system so that everything will work in harmony."

{PROGRESS ON GOAL 1.2.2}

{TSG-4 revised} "Counter should be designed and verified over this next week. +++ Complete counter by 3rd March +++"

{PROGRESS ON GOAL 1.2.1.2}
"I/O port verified"

Along with the diary, S8 encloses programs and CAD timing diagrams to indicate the verification work that he has been engaged in. S8 describes and evaluates this information as follows:

"-Simulation program to give full verification.
-Timing diagram of whole verification.
-[Marker pen] Highlight of counting and a short error state which occurs due to different propagation delays due to rising edge or falling edge propagation delay of the cell. These should present no problems during operation since they are very short (1.2ns) and all data is triggered on a clock edge.
-Highlight recovery from tristate condition.
-Highlight activation of tristate condition
-12ns propagation delay through the I/O port
-Effect of shifting data transition i) 30ns after clock edge ii) 10ns after clock edge. No effect on operation as expected."

{GOAL 1.2.1.2 ATTAINED}

{OBG-2 repeated & elaborated}
"Evaluate counter designs used on commercial components to determine 'best design' for use on the DMA unit as a 32-bit synchronous counter"

{goal pursued}

PROBLEMS "Aim to have designed the counter today +++ [but] system is shut down on project day (Tues. 3rd March) for half a day +++ therefore unlikely to complete the counter [today]."

PLANNED METHOD (for tackling problem) "Will design on paper and in my mind, then, using existing programs for verification on I/O port, develop the verification program for the counter ready for efficient use of the system when it returns."

At this point, with only one module of the DMA unit having been successfully designed and tested, S8's ceases to maintain his diary entries. This is presumably because the project deadline is looming close and he is having to devote his efforts toward the completion of his design work. Fortunately, however, S8 documents some aspects of the remaining design within his Laboratory book. Although no attempt has been made to structure this material within this DBG, some comment is made on TS's work during this final project phase within the main text of the thesis (see section 4.4.3).

A.3.3. MM'S DESIGN BEHAVIOUR GRAPH

1 To design and implement a device for measuring electro-oculograms which eliminates errors arising in conventional methods of detection from ocular artifacts.

{LONG-TERM GOAL: ONGOING PURSUAL}

> This inferred goal is presumed to be set for MM by his supervisor who in all probability also details the basic solution concept for the problem. This solution involves the use 'impedence change' within the eye to measure the electro-oculogram (EOG). MM outlines the functionality of the intended device as involving the injection of a high-frequency, low-value current into the eye and the subsequent extraction of the modulated signal coming out to reveal the impedence change that has occurred.

{PROGRESS ON GOAL 1}

PLANNED METHOD "My project is to design the 'black box' to send the current into the eye and also to demodulate the resulting signal. At the commencement of this diary a reasonable idea of what is to go in the 'black box' is known, but the circuit needs to be designed, components bought, and the resulting finished circuit tested, and compared with conventional methods of detection."

> The PLANNED METHOD stated above may be viewed as the all-encompassing plan underlying S6's project work. It can be broken down into three composite design/implementation sub-goals which may be stated as below.

1.1 "+++ design the 'black box' to send the current into the eye and also to demodulate the resulting signal +++"

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}
"I've got a rough idea what's to go in it [i.e. the 'black box] +++ there are going to be three chips, which are going to be: an instrumentation amplifier; I'm going to need an oscillator of some kind to produce the high frequency current; and obviously there will be a demodulating chip as well." [Interview 4/11/86]

DECISIONS "Obviously I could have designed the actual demodulator and things like that, but Dr K----- said it would be best just to buy a chip that does that.." [Interview 4/11/86]

RATIONALE "there's no point designing it from scratch using discrete components if you can buy something that does the things for you." [Interview 4/11/86]

1.2 Buy components and construct the circuit

{FUTURE GOAL: IMMEDIATE PURSUAL NOT INTENDED}

1.3 Test the finished circuit

{FUTURE GOAL: IMMEDIATE PURSUAL NOT INTENDED}

1.1.1 "The aim of this week mainly is to pick the correct components for the circuit, ready for assembly in the forthcoming weeks"

{GOAL PURSUED}

METHOD USED "When the general outline of what was to go into the 'black box' was decided upon the obvious step was to go to each block (i.e. demodulator, amplifier, constant-current oscilllator) and decide on what circuits are needed. This is just a matter of reading and finding the required chips to achieve the operation of the circuit in data books."

★ *KAG-1* Read data books to enable choice of suitable chips

{goal pursued}

"Most of my time this week was spent in the Project Lab looking at data books to pick suitable components. As there are not many demodulator chips available, it is not such a difficult job, as a standard setup is needed."

"Dr K----- has given me a few chips to look at and I've got the application notes in the data books, and they seem to be allright for the job - for the levels of current I need and the frequency range." [Interview 4/11/86]

{PROGRESS ON GOAL 1.1.1}

"+++ I think I have found the right combination [of chips], and the next problem is to put a design on paper using these components."

S6's comment above doesn't appear to be consisitent with next week's statement that he is still aiming to choose the main components for the circuit.

GENERAL CONSTRAINT "+++ to keep in the budget available to us.."

✱ *TSG-1* "The long term aim is to actually finish the building of the circuit by the end of term, ready for testing next term"

__{GOAL 1.1.1 REPEATED}__ "The aims this week +++ were to actually choose the main components for my circuit, and hence get a design on paper to discuss with Dr K-----. Then the sending off [for the components], and subsequent building of my circuit could take place"

__{GOAL PURSUED}__
"Went into the project lab to look at the specifications of the components I was interested in."

1.1.1.1 Select amplifier

{__GOAL PURSUED & ATTAINED__}

1.1.1.2 Select demodulator

{__GOAL PURSUED & ATTAINED__

1.1.1.3 Select constant current oscillator

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}
PROBLEM "Most [components] seemed OK for the job, but one in particular is holding me up, the 'constant-current oscillator' - to produce the current to pass into the eye. Apparently there is not one available."
"The main problem came up when I could not find a constant-current oscillator (I can find an oscillator and also a constant current-source but not something that does both together)."

★ *KAG-2* Seek expert advice on constant-current oscillator problem

{goal pursued}
"When the main problem arose, I just went up to the Communication Engineering department to ask up there."

PROBLEM "As (the main person who deals with the field I am interested in) was busy and so I was told he would be free later in the week, so maybe a solution can be found there. Unfortunately, went home early in the week so have not had the opportunity to see him. Maybe next week."

DECISION "Decided to see Dr K----- about the problem +++"

PROBLEMS "+++ couldn't find him [Dr K-----] +++ so things are at a bit of a standstill at the moment +++ Overall, did not achieve much this week, due to not being able to discuss the problem, and also because I went home for the weekend."

DECISION
✱ *TSG-2* "Will try to sort out the problems next week"

IDEA "May well have to build one [an oscillator] to my specifications, instead of finding a chip to do the job."

COMMENT (relating to demodulator)
IDEA "I have also seen a method of getting my finished signal using a filter instead of demodulating the signal."

QUESTION "Is a demodulator really necessary?"

★ *KAG-3* "Must discuss [this design option with Dr K-----]"

{goal not immediately pursued}

COMMENT "An abstract that I sent for from the library came through this week, dealing with aspects of my project (interfaced with a micro), but was not much help as they did not go into much depth on the subject. Good from the point of view that an impedence method can be successfully linked with a micro. This might lead to ideas for future research.

{PROGRESS ON GOAL 1.1.1.3 & progress on KAG-2}
"Meeting [with Dr K-----] scheduled for Tuesday 18th +++ I still have the problem with my oscillator circuit, but I have been given a book to look through on op-amp circuits to maybe use a circuit in there."

CONSTRAINT "This is of great importance as term-time is now running short!"

DECISION & RATIONALE "My main decision this week was to back off a little on the project work as other aspects of the course took precedence (i.e. report deadlines)."

{TSG-2 revised} "Will sort things out next week"

{PROGRESS ON GOAL 1.1.1.3 & progress on KAG-2}
"The meeting with Dr K----- was very fruitful. A circuit was found, we think, that will perform the required task for us. I will have to construct it (i.e. there is no one chip to perform the task), quite simple circuit though."

{KAG-2 attained}

DECISION & RATIONALE "A minor alteration was needed on the found circuit, (i.e. that the circuit found was used for dc (one level) and I need an oscillating input (ac). So putting an oscillator in instead of a battery was an obvious choice. Hopefully this will work.

METHOD USED "The method used in finding the circuit was to look through various text-books to find a circuit that nearly met the requirements and, under the supervision of my supervisor, finding a way of changing it for our needs."

COMMENT "At this stage, therefore, we believe the circuit should work, but in practice - who knows?"

From the interview of 9/12/86 it emerges that S6 did manage to discuss the oscillator problem with AS of the Department of Communications Engineering. AS "put forward a few ideas" but they were not evaluated because "fortunately we [S6 and his supervisor] found a circuitr which we could work on".

{GOAL 1.1.1.3 ATTAINED}

1.1.2 "+++ to get some sort of idea of a complete circuit configuration"

{GOAL PURSUED}
"Generally a good week, now generating the design (in theory) of the circuit."

{PROGRESS ON GOAL 1.1.1.2 & progress on KAG-3}

Within the diary S6 makes no further reference to this notion that maybe a demodulator isn't necessary. In the interview of 9/12/86, however, S6 is asked if he remembers questioning the need to use a demodulator. His reply is as follows

COMMENT "Yes.. I was looking at some passed papers and there was a few lines that I read that and I thought, "Well do I need a demodulator?" and I found out that I really did - it was just a different application they were using .. it wasn't really what I wanted .. but it seemed curious to me that they didn't mention a demodulator in their circuit, but it was a different sort of application." [Interview 9/12/86]

(1.2.1) "+++ send off for the required components"

{GOAL NOT IMMEDIATELY PURSUED} because of:
PROBLEM "Did not have enough time to send for the components though."

* *TSG-3* "Will do this next week"

{GOAL 1.2.1 REPEATED} "+++ I am aiming to order all of the components required for my circuit +++"

{GOAL PURSUED}
"The bulk of the components were ordered +++"

{GOAL 1.1.2 REPEATED} "+++ also [aiming] to put a constructional plan of the circuit down on paper"

{GOAL PURSUED}
PROBLEM "One quite large problem occurred when trying to get a constructional layout on to paper from the various circuit diagrams of the parts of the circuit. They look quite simple in circuit diagram form, but when all connections have to be considered, it is quite a daunting task. Hopefully my solution will work."

{GOAL 1.1.2 ATTAINED}

METHOD USED "The way the circuit was put into constructional form was to go from the circuit diagram, checking each pin number in turn, to see where it is connected to. Once that has been put on to paper, the new circuit can be moved around from there to tidy it up."

1.2.2 Construct circuit

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL} ***OKG-1*** Consider techniques for the actual construction of the circuit

{goal pursued}
DECISION & RATIONALE "A big decision this week has been to decide which method I will use when mounting the components on to the board - (whether to use solder or to use wire-wrap techniques). The latter I have decided to use due to the fact that if the circuit does not work properly the components can be easier to move into a new position +++ [additionally] The problem of cutting out tracks on a veroboard to stop conduction to parts of the circuit not needed has been eliminated as a 'wire wrap' board is to be used."

★ ***KAG-4*** "Must see Dr K----- about special 'wire-wrap' techniques as I have never used this technique before"

{goal not immediately pursued}

● *PDG-1* "I intend to put more background information of my project into a newly acquired record book in order to make the writing up of the project easier when the time comes"

{goal not immediately pursued}
"It is not such an important task at the moment. Firstly the circuit!"

{PROGRESS ON GOAL 1.2.2}

So states that his "aims were actually to construct the circuit this week, but things haven't quite worked out." This is clearly because he hasn't yet acquired all of the components necessary to construct the circuit.

{PROGRESS ON GOAL 1.2.1}
"Ordered the rest of the components this week, but due to the process of ordering (i.e. getting signatures off supervisors etc) the ordering was done later on in the week, so they will not arrive until later on next week."

METHOD USED "If a problem came up, with what sort of component to use, the usual practice was to ask our technical supervisor for assistance."

PROBLEM "The biggest problem was trying to find Dr K----- for his signature to order the components. At least they are ordered now."

COMMENT "The only thing I can do now is to wait until the components arrive next week sometime."

{GOAL 1.2.1 ATTAINED}

{PROGRESS ON GOAL 1.2.2}
"The components have now arrived +++"

✱ *TSG-4* "+++ now I hope to construct at least some of the circuit before I go away on my Christmas break"

COMMENT (on general progress) "Looks like I will be slightly behind schedule when I break up for Christmas. Things are looking up though as next term we get more time for project work. At least I will have all my components lined up to begin construction."

{PROGRESS ON GOAL 1.2.2}
"I did manage to construct some of the circuit before I went home."

PROBLEMS "The biggest problem was the fact that wire wrapping techniques were to be used, and I had never used this before. The first few connections were a bit dodgy, but after a while the technique became easier and slowly but surely a circuit began to take shape."

METHODS USED "+++ a layout was put down already on paper +++ and it was just a matter of putting this actually in hardware terms."
"For the actual construction itself, a technique was to draw a duplicate circuit down as I was going on so as to keep track of the connections being made. This is very useful, as the name implies (wire wrap), a lot of wire is used, and it is easy to miss a connection and it would be difficult to trace an error at the end of the construction. A technician advised me as to this technique, through trial and error himself."

{progress on PDG-1}
"I also completed some theoretical work as well as background to help when writing up comes along."

COMMENT (on general progress) "I am well pleased going into the Christmas break, all in all. I will be ready to give it a good go when I get back. I don't plan on doing any project work over the holiday, as I only have 2 weeks, and I have other things to do. Anyway I have no wire wrap equipment available to me at home."

{PROGRESS ON GOAL 1.2.2}

The Christmas vacation is now over and S6 is aiming "To get as far as possible on the construction of the board."

COMMENT (on progress) "Got on quite well, but have not quite finished the construction yet +++ No real problems. Just a matter of time to finish the construction."

{PROGRESS ON GOAL 1.2.2}

* *TSG-5* "I hope to completely finish the construction this week"

COMMENT (on progress) "The circuit is now built and I am very pleased with the results. Below is a circuit diagram of the complete circuit [See Appendix C for circuit diagram]"

{GOAL 1.2.2 ATTAINED}

{GOAL 1.3 RESET} Test the circuit

{GOAL NOT IMMEDIATELY PURSUED}
* *TSG-6* "+++ start the testing next week"

{GOAL 1.3 ELABORATED} "The main activity this week will be to start testing the circuit, firstly without any of the ICs in to see whether I have the right voltages and currents available, and then to plug them all in and test it"

{GOAL PURSUED}
METHOD USED "Firstly the circuit was probed to see whether the right voltages were there (i.e. supply rails and ground) and I did actually find a few mistakes, so it was a good idea to do this. The chips were then plugged in and voltage levels monitored with a variable resistor acting as the subject. Voltages were not out of order +++"

PLANNED METHOD "+++ now I must connect a scope up to the circuit to see the waveforms."

PROBLEM "A problem came when the scope was connected into the circuit, as I couldn't get any really good waveforms at all. It is likely that I haven't set the scope up properly (or on a bleaker note the circuit may not be working!)

* *TSG-7* "+++ I will have a[nother] go [with the scope] next week. (My main priority is to get some good waveforms out)"

IDEAS "+++ because you are using a human subject - a patient - you've got to think about the safety of the patient, because a current is going into the eye-ball you've got to make sure that it's not to large to affect them .. And also once I've done this design - if it works OK - I've got to think about what would hapen if something breaks down in the circuit - are you going to get large currents surging around.. I've got to have a circuit breaker just in case that occurrs .. those are considerations after .. but obviously once I get the circuit down, I'm not going to go and plug it into a patient, I'm going to have to sort of simulate a patient." [Interview 9/12/86]

{PROGRESS ON GOAL 1.3}

PROBLEMS "Continued testing, but still no O/P. +++ Not sure whether it is the way the leads are connected or the actual circuit. Probably the latter, but I must be persistent."

METHOD USED "With a clear and concise circuit diagram, the circuit must be probed piece by piece to see whether the required voltages are present and the required pins are connected. It would help enormously if I could get an O/P on the scope."

★ *KAG-5* "+++ ask some questions to Dr K----- about the problem that I cannot get the scope to give me the correct O/P"

{goal pursued}

{PROGRESS ON GOAL 1.3 & progress on KAG-5}

"Found a fault in the amplifier, so that is a start (i.e. -ve I/P was not connected up) but that should not affect the fact that no O/P on the earlier part of the circuit was found on the scope."

"Did not see Dr K----- until it was too late, but he told me to go through the circuit again step-by-step with a clear circuit diagram and see if the correct voltages are present etc."

{KAG-5 attained}

GENERAL CONSTRAINT "Well, I have one week until the external examiner comes round for a chat, so I want something to show him. I want to really get down to it next week and produce something solid to show."

{progress on PDG-1}
"+++ did some theoretical writing up as well."

1.3.1 "The aim this week is to get something to show up on the scope, and to get at least the modulation of the carrier signal to show up on the scope"

{GOAL PURSUED} "Found out what was wrong with the O/P of the generator. The whole thing was working except that as the generator was connected to the demodulator, it was somehow loading the O/P to give rubbish. The first part of the circuit now works fine, showing the actual modulation.

METHOD USED "Originally when the O/P of the generator was not working properly I decided to disconnect the demodulator to see what would happen, and indeed it was its fault."

DECISION "Will deal with the demodulation at a later stage."

COMMENT "Very good week this week. I can see that something is indeed working and I have something to show the external examiner.

{GOAL 1.3.1 ATTAINED}

1.3.2 "After the circuit has been examined I will concentrate on the demodulator problem"

{FUTURE GOAL: IMMEDIATE PURSUAL NOT INTENDED}

A.3.4. AD'S DESIGN BEHAVIOUR GRAPH

1 Design and implement a stand-alone, programmable PCB-drill

{LONG-TERM GOAL: ONGOING PURSUAL}

S4 provides a fuller description of the device that he is aiming to design and implement as follows: "Yes. It's a PCB - printed circuit board - drill which is controlled by stepper motors in three dimensions by stepper motors +++ and it's a small micro stand-alone thing which can be programmed by a BBC computer or on its own. You put in the hole locations - where you want the holes drilled - and hopefully when it's finished it will run through the program drilling the holes. So once you've programmed it once that's all you've got to do". [Interview 4/11/86]

1.1 "To complete the design and layout of the display and keyboard part of the circuit +++"

{GOAL PURSUED}
"All of the project time for this week (lab time) was employed drafting artwork transparencies for a printed circuit board"

1.2 Choose processor and design associated circuitry

{INTERMEDIATE-TERM GOAL: ONGOING PURSUAL}

1.2.1 "To finalise the choice of processor and/or components associated with it"

{GOAL PURSUED}
"Other time outside of the actual lab period was spent researching the components to be used in the microprocessor circuit, including the processor section of the circuit and the stepper motor drive circuit was researched into"

PROBLEMS "Problems arose when the choice of memory chips for the processor circuit were investigated; when the processor is running at its specified rate (4Mhz) the time given to access the EPROM part of the memory is small and through examination of data sheets very few EPROMS could give such a small memory access time."

DECISION & RATIONALE "The problem of the slow access time on the EPROM was overcome by the decision to slow the processor clock down, due to the fact that there is no real need for the processor to run at its full 4MHz and so the slower clock rate will not reduce the systems performance at all."

1.3 Consider boards for construction of processor circuit

{GOAL PURSUED}
CONSTRAINT "The board the processor circuit is to be built on was to be a Euroboard using a wirewrapping technique. However, the relatively high cost of a Euroboard may require some other type of construction to be used."

1.4 Consider the design of the stepper motor drive circuit

{GOAL PURSUED}
"+++ the stepper motor drive circuit was researched into."

DECISION "The drive method used was decided, that being, the low current capability of the TTL logic system being amplified by transistors, and a fast step rate being achieved by incorporating PWM drive into the circuit. The 'low' state of the TTL is to be used for the step of the motor due to its higher current capability."

* *TSG-1* "To determine the timescale in completing parts of the project, including the finishing of the actual construction of the hardware, and the times for completing the various stages of software"

{goal pursued}

> Note that TSG-1 actually falls outside the definition of a TSG as stipulated under the present goal taxonomy. Sill, however, it seems appropriate to classify this goal as a TSG since it clearly relates to the scheduling of design activities.

1.4.1 "The type of interface between the TTL levels and the stepper motors was to be decided on"

{GOAL PURSUED} While S4 has actually made the major decision in Week 1 to include PWM drive as part of the interface circuit, it appears that this week he is reasserting the decision as well as clarifying the finer details of the circuit design (see 'Decisions' below). Additionally S4 provides some rather garbelled comments on the constraints that were influential in this circuit design work.

CONSTRAINTS "The constraints behind the work completed this week were the stepping rate for the motors, due to the fact that the design can only be proved on a horizontal mill with x & y movement controlled by stepping motors, the resolution per step being 1/200 of a millimetre, hence for any appreciable speed of movement the stepping rate has to be as high as possible."
"The power drive circuitry has also got to ensure that the logic circuitry is not damaged should any fault conditions occur."

DECISIONS "To increase the stepping rate of the motor as much as possible it was decided to use a PWM system, as mentioned previously; a circuit was chosen to implement the PWM system."
"The logic circuit was decided to be protected from the power transistors using an initial opto-isolator on each winding of each stepper motor before the power transistors, to isolate logic circuitry electrically."

{GOAL 1.1 REPEATED} "The aim of activity this week was to finish the artwork for the keyboard/display circuit, and to submit for construction"

{GOAL PURSUED}
"Time this week was spent finishing off the transparency for the display/keyboard pcb +++"

It appears that S4 then submitted this artwork for construction.

{GOAL 1.1 ATTAINED}

1.2.2

"Similarly [i.e. similar to GOAL 1.1] a wirewrap artwork for a pcb was to be drafted for the processor circuit"

{GOAL PURSUED} "Time this week was spent +++ drafting an artwork for processor pcb/wirewrap board +++"

{GOAL PURSUED & ATTAINED}

1.2.1.1 Decide on the number of IO sockets etc. for the wirewrap processor board

{GOAL PURSUED}

CONSTRAINTS "For the completion of these artworks, decisions on the number of IO sockets etc. for the wirewrap processor board needed to be made +++"

{GOAL 1.2.1.1 ATTAINED}

1.2.3 "+++ the type of interconnections between boards needed to be decided upon"

{GOAL PURSUED}

"The type of connections +++ between boards were decided upon, the type for the processor board being of similar design as those on the BBC user port (which is to be used as part of the project)."

{GOAL 1.2.3 ATTAINED}

1.5 "The aims of the project schedule this week were to finish building the display/keyboard circuit and to complete leads enabling it to be fitted to the user port of the 380Z research machine"

[GOAL PURSUED]
"Drilling etched pcb boards"

PROBLEM "Upon collection of the pcb boards and the subsequent drilling of them it was discovered that instructions given to the technicians on the positioning of the transparency on the board were incorrect and in fact the transparency had been etched on the wrong side, and hence the design was completely back to front."

DECISION "As the pcb was incorrect a new one was commissioned, a simple case of reversing the transparency; this will be available for the next lab session."

[progress on TSG-1] "A timescale was also drawn up showing dates when various stages of the project are expected to be finished, a brief description of the decisions taken so far along with the reasons behind these decisions was written."

[TSG-1 attained]

{GOAL 1.2.2 REPEATED} "the wiring diagram for the processor board was to be completed"

{GOAL PURSUED & ATTAINED}

1.6 Implement processor pcb

{GOAL PURSUED}

1.6.1 "+++ some of the initial wire wrapping connections [were] to be scheduled (i.e. address busses, decoding data buses) +++"

{GOAL NOT IMMEDIATELY PURSUED}
COMMENT "Scoring wiring system for processor board"

1.7 "+++ all of the final decisions for the interconnections between circuits were to be decided upon +++"

{GOAL NOT IMMEDIATELY PURSUED}

1.4.2 "the artwork and final circuit for the drive circuitry was to be designed"

{GOAL PURSUED}

DECISION & RATIONALE "+++ the drive system circuitry was to be redesigned using a SA1087 stepper motor control chip as further price investigation showed that no significant cost saving was established using discrete logic components." "Upon discovery of a much cheaper source of stepper motor drive chips it was decided to use these specialist chips rather than the discrete logic chips, as there is no significant saving in cost for the discrete chips and using this chip will save considerable time on the construction of the circuit and will reduce the need for current amplification (i.e. one power transistor instead of two)."

DECISIONS & RATIONALES "+++ upon discussion with the mechanical department the fact came to light that drive circuitry already existed for the mill and so there was no need to construct/design a new one."
"The provision of a drive circuit for the motors, although not completely necessary, was decided to be carried on with, even if only a paper design for inclusion in the final project report, as the existing circuit didn't include a PWM system to increase the stepping rate."

{GOAL 1.5 REPEATED} "The main objectives were to finish the display/keyboard construction +++"

{GOAL PURSUED}
METHOD USED "The construction of the keyboard/display was a case of initially drilling the holes and then soldering in components."

{1.6.1 REPEATED} "to start the wire wrapping of the processor board"

{GOAL PURSUED}
METHOD USED "The wiring of the board was undertaken by initially working out a wiring schedule listing the chips and the pins that need to be interconnected. The wiring was carried out using a speed wire system which involves wrapping wire around the pins of the IC sockets; this process splits the insulation on the wire, and eliminates the need to bare the wire, the wire is then wrapped around the next pin etc, until all of the connections for one line have been made."

{GOAL 1.5 REPEATED} "The aims were to finish the construction of the display board +++"

{GOAL PURSUED & ATTAINED}

1.8 "Verify its [the keyboard/display board's] operation"

{GOAL PURSUED}

METHODS USED & PROBLEMS "Upon the finish of the construction of the keyboard/display board its operation was tested by putting predetermined input conditions on the inputs to the display screen; when this was done it was found that the desired effect was not forthcoming and upon further inspection it was found that some short circuits were present on the board; these were found by removing the display driver and testing individual segments of an individual display. The shorts were eventually found and the appropriate steps taken to correct them."
The keyboard section was then tested by monitoring the various outputs of the circuit, the operation was not as expected and so closer testing had to be carried out. The correct outputs were being obtained from the actual keyboard chip (740922) and it was found that a wiring fault existed at the (7400). This was corrected and the circuit's correct operation resulted."

PROBLEM "The normal values of the oscillator and debounce capacitors for the keyboard chip were found to give too slow a response (ie the keys had to 'held down' rather than tapped down) +++"

COMMENT "+++ so in the future new values of capacitor will need to be selected."

1.6.2 "The wiring schedule for the completion of the processor board was also to be finished"

{GOAL PURSUED}

1.7.1 "The interface leads to the 380Z research machine were to be made so that development of the software could be started in the near future."

{GOAL PURSUED}
"The interface leads to connect the keyboard/display to the 380Z research machine were completed."

{GOAL 1.7.1 ATTAINED}

METHOD USED "The pinout of the 380Z input/output port was obtained and suitable leads constructed for interface to it +++"

1.7.2 "The actual construction of the interface lead to the power driving circuitry was to be designed +++"

ELABORATION (of GOAL) "External power supplies will be needed to power the circuit as the 380Z power is fully used in the actual reading. The external supplies however will still need to be referenced to the 380Z supplies."

★ *{GOAL NOT IMMEDIATELY PURSUED}*
KAG-1 "+++ knowledge of the type of connections on the circuit would need to be gained."

{GOAL 1.8 REPEATED & ELABORATED} "The aims and objectives were to verify the correct operation of the display/keyboard and to write an assembly language program to display 6 BCD (Binary Coded Decimal) numbers held in 3 bytes of data, for use in the final processor system."

{GOAL PURSUED}
"The keyboard and display were tested using a simple program on the 380Z."

PROBLEMS "The use of the 380Z was learned +++ Upon the interfacing of the display/keyboard, problems were found on both sides of the circuit.
The display circuit, while operating correctly, was unsatisfactory as the display was faint due to the short on time compared with off time.
The keyboard was seen to operate while examined on the oscilloscope, but when entering data into the display some strange characters were displayed."
"+++ the 5th digit of the display was found to have a segment missing, the LED was found to have no fault and so the fault must be in the pcb. Also '0' would not register on the displays."

DECISIONS & RATIONALES
"The faint display can hopefully be rectified in two possible ways. These include: 1) using a lower value of current limiting resistors on the LED drivers, thus creating a brighter display, and 2) increasing the on time of each character by incorporating a time delay into the software program."

1.8.1 "The keyboard problems will need further examination also, determining exactly what is wrong with the current and hence trying to determine some solutions to the problem."

{GOAL NOT IMMEDIATELY PURSUED}

1.7.3 "It was found out that the stepper motor interface to the microprocessor would now have to be constructed +++"

{GOAL PURSUED}
RATIONALE "+++ the reason for this was that the electrical and electronic [engineering] department had bought a small vertical mill, similar to the one that was initially to be used in the mechanical department, this was to have stepper motors fitted and here I would now need to build the appropriate interfaces."

TSG-2 "After discovering the need for the interfaces it was decided to use all of this week's project time on designing and planning the construction of the interfaces "

{goal pursued}

DECISIONS & RATIONALES "Earlier in the project, stepper motor drives had been investigated, and so there was very little work to be done in the research field +++ as a lot of time would need to be spent developing a stepper motor drive system including chopper arms, or dual voltage drive it was decided to use a simple drive circuit. The motor drive logic initially was to be constructed using discrete IC's due to a saving in cost, however upon further investigation a cheaper sort of motor driver chip (SAA1027) was found. Also the complete stepper motor interface was to be paid for out of the department's research budget as the new interface could be communally used after the completion of the project. The final choice was made, and the circuit employed by the mechanical department was to be used, this was used as the circuit had already been proven and so no time would have to be taken in debugging faults in a different circuit. The final unit was to be boxed, the artwork was finished and submitted for construction before the Christmas vacation as were all of the component lists were ordered so as work on construction of the unit could begin as soon as possible."

1.9 "[Aim] To determine the operation of the system from start up, including the operation of the keyboard."

{Goal not immediately pursued}

1.10 Write machine code program

{GOAL PURSUED}

ELABORATION "As no more constructional work could be completed it was decided to start writing the machine code program. An initial design criteria had already been built up consisting of flow charts of various parts of the control program [but] the fine details and the actual implementation needed to be developed."

At this point in his project S4 ceases to be involved in work relating to electronics design and implementation and instead turns toward the software aspects of his project. No attempt has been made to structure this material within the DBG because of its limited bearing on the processes involved in electronics design.

Appendix B

Professional Design Study

Appendix B. Professional Design Study

Page

B.1. PROBLEM SPECIFICATION PRESENTED TO SUBJECTS

B.1.1. PROBLEM SPECIFICATION

The following is the problem specification that was presented to the company designers who took part in this study.

You are required to design an integrated circuit that can perform the following computer vision task:

Process an area of RAM memory that contains a 2-D TV image. The chip will be sent two X,Y coordinate pairs and constants N, M and λ. The coordinate pairs X,Y start and X,Y end define the position of a line vector drawn over the memory. The chip then has to calculate:-

(1) N coordinate pairs along the line vector

(2) At each coordinate pair so derived, generate the appropriate coordinates for a line vector drawn at a Normal to the given line vector. Using stepping factor λ form M coordinate pairs. (Refer to figure 1 below).

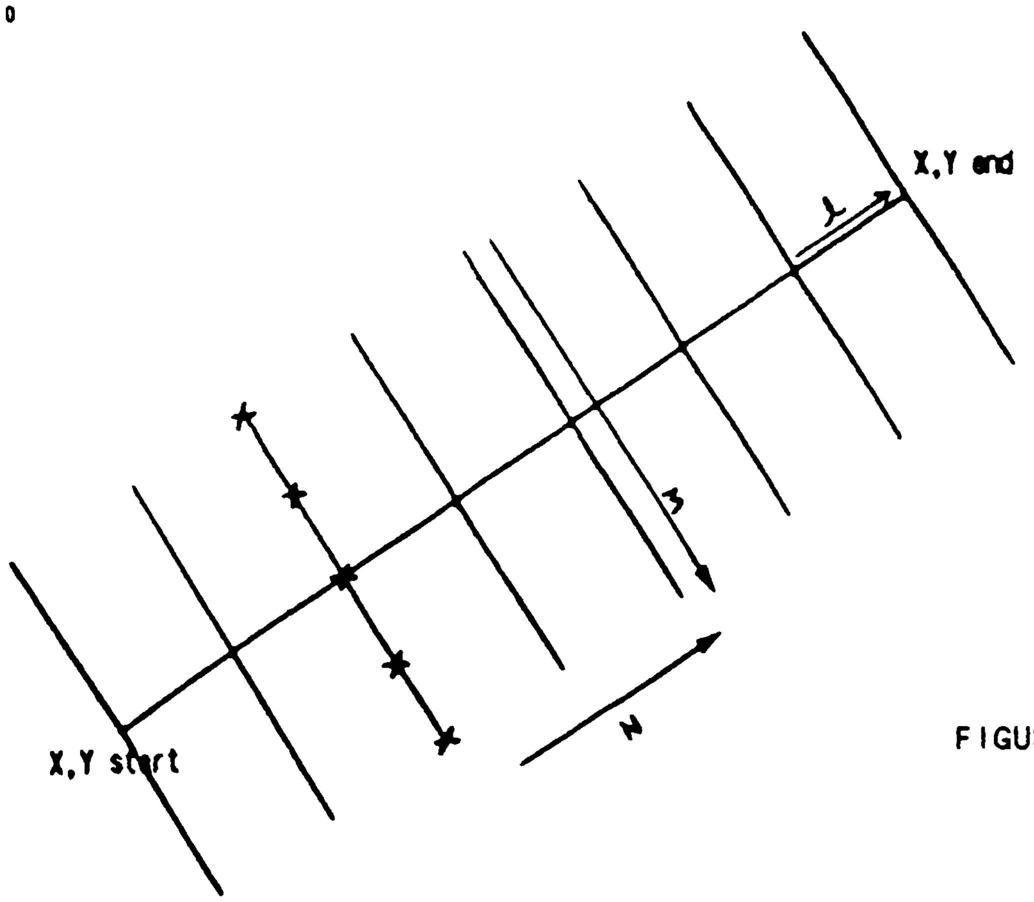
(3) At each Normal coordinate pair, fetch the nearest pixel from memory and summate its value according to the expressions below, generating two data items for each normal vector, g(x) and h(x). These are returned to the host.

$$g_{(x)} = \sum_{i=0}^{i=m} x_{(i)} \mathrm{Sin}(k.i)$$

$$h_{(x)} = \sum_{i=0}^{i=m} x_{(i)} \mathrm{Cos}(k.i)$$

Where $k = \dfrac{360}{M}$

and $x_{(i)}$ is current pixel



N = 8

M = 5

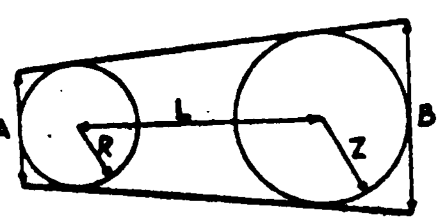
FIGURE 1

Note: Image data is 8 bits deep and image array is at least 512 by 512 points.

B.1.1. HELP SHEETS

All designers taking part in the study were presented with the following help sheets which depicted potentially useful mathematical formulae.

FORMULAE FOR TAPERS



T = Taper per inch

$$L = \frac{Z - R}{T}\sqrt{1 + T^2} \qquad \text{Taper per foot} = 24\left[\frac{Z - R}{\sqrt{L^2 - (Z - R)^2}}\right]$$

$$R = \frac{A}{L}\left[\sqrt{L^2 + (B - A)^2} + (B - A)\right]$$

$$Z = \frac{B}{L}\left[\sqrt{L^2 + (B - A)^2} - (B - A)\right]$$

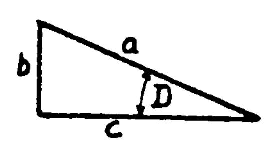
$$A = R\sqrt{\frac{L - (Z - R)}{L + (Z - R)}} \qquad B = Z\sqrt{\frac{L + (Z - R)}{L - (Z - R)}}$$

JSEFUL CONSTANTS

$= 3.14159$	$g = 32.16$
$3 + \pi = .95492$	$1 + g = .01555$
$^2 = 9.8696$	$\pi + \sqrt{g} = .55399$
$\sqrt{\pi} = 1.77245$	$\sqrt[3]{6 + \pi} = 1.2407$
$+\sqrt[3]{\pi} = .68278$	$\pi + 3 = 1.0472$
$\pi + 4 = .7854$	$1 + \pi = .31831$
$g = 64.32$	$1 + \pi^2 = .10132$
$1 + \sqrt{g} = .17634$	$\sqrt[3]{\pi} = 1.46459$
$+ 180 = .01745$	$\sqrt[3]{3 + 4\pi} = .62035$
$2\pi = 6.28318$	$\sqrt{2g} = 8.01998$
$\pi + 3 = 4.18879$	$g^2 = 1034.226$
$\pi^3 = 31.00628$	$e = 2.71928$
$+\sqrt{\pi} = .56419$	$180° + \pi = 57.2958°$
$\sqrt[3]{\pi^3} = 2.14503$	

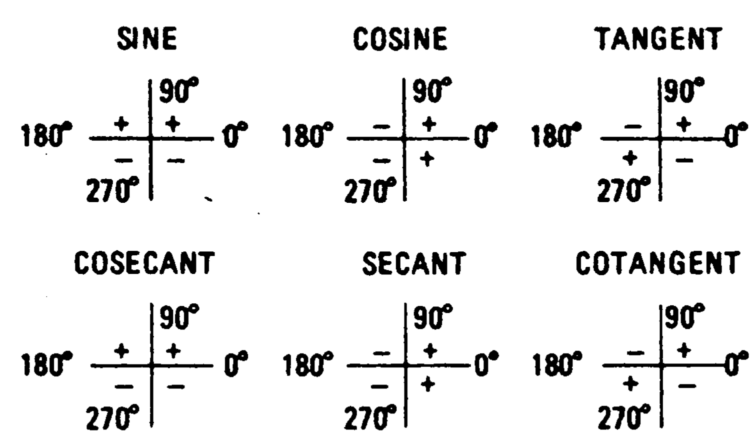
TRIGONOMETRY

DEFINITIONS



b/a = Sine D	b/c = Tangent D
c/a = Cosine D	a/b = Cosecant D
c/b = Cotangent D	a/c = Secant D

CHANGE IN SIGN OF TRIGONOMETRICAL FUNCTIONS



USEFUL FORMULAE

$$\sin^2 A + \cos^2 A = 1 \qquad \tan A = \frac{\sin A}{\cos A} = \frac{1}{\cot A}$$

$$\cot A = \frac{\cos A}{\sin A} = \frac{1}{\tan A} \qquad \sec A = \frac{1}{\cos A} \qquad \operatorname{cosec} A = \frac{1}{\sin A}$$

$$\sin A = \sqrt{1 - \cos^2 A} = \frac{\tan A}{\sqrt{1 + \tan^2 A}} = \frac{1}{\sqrt{1 + \cot^2 A}}$$

$$\cos A = \sqrt{1 - \sin^2 A} = \frac{\cot A}{\sqrt{1 + \cot^2 A}} = \frac{1}{\sqrt{1 + \tan^2 A}}$$

$\sin(A + B) + \sin(A - B) = 2 \sin A \cos B$

$\sin(A + B) - \sin(A - B) = 2 \cos A \sin B$

$\cos(A + B) + \cos(A - B) = 2 \cos A \cos B$

$\cos(A - B) - \cos(A + B) = 2 \sin A \sin B$

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$$
$$\cos(A \pm B) = \cos A \cos B \mp \sin A \sin B$$

$$\tan(A \pm B) = \frac{\tan A \pm \tan B}{1 \mp \tan A \tan B} \qquad \cot(A \pm B) = \frac{\cot A \cot B \mp 1}{\cot B \pm \cot A}$$

$$\tan A \pm \tan B = \frac{\sin(A \pm B)}{\cos A \cos B} \qquad \cot A \pm \cot B = \frac{\sin(B \pm A)}{\sin A \sin B}$$

$$\sin^2 A - \sin^2 B = \cos^2 B - \cos^2 A = \sin(A + B)\sin(A - B)$$
$$\cos^2 A - \sin^2 B = \cos^2 B - \sin^2 A = \cos(A + B)\cos(A - B)$$

$$\sin A \sin B = \tfrac{1}{2}\cos(A - B) - \tfrac{1}{2}\cos(A + B)$$
$$\sin A \cos B = \tfrac{1}{2}\sin(A + B) + \tfrac{1}{2}\sin(A - B)$$

$$\tan A \tan B = \frac{\tan A + \tan B}{\cot A + \cot B} \qquad \cot A \cot B = \frac{\cot A + \cot B}{\tan A + \tan B}$$

$$\sin A = 2 \sin \tfrac{1}{2}A \cos \tfrac{1}{2}A \qquad \sin 2A = 2 \sin A \cos A$$
$$\cos 2A = \cos^2 A - \sin^2 A = 1 - 2\sin^2 A = 2\cos^2 A - 1$$

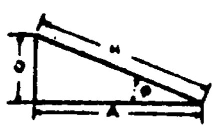
$$\tan 2A = \frac{2 \tan A}{1 - \tan^2 A} = \frac{2}{\cot A - \tan A} \qquad \sin A = \frac{2 \tan \tfrac{1}{2}A}{1 + \tan^2 \tfrac{1}{2}A}$$

$$\cot 2A = \frac{\cot^2 A - 1}{2 \cot A} = \frac{\cot A - \tan B}{2} \qquad \cos A = \frac{1 - \tan^2 \tfrac{1}{2}A}{1 + \tan^2 \tfrac{1}{2}A}$$

$$\sin 3A = 3 \sin A - 4 \sin^3 A$$

$$\cos 3A = 4\cos^3 A - 3\cos A \qquad \tan 3A = \frac{3 \tan A - \tan^3 A}{1 - 3\tan^2 A}$$

SOLUTION OF RIGHT-ANGLED TRIANGLES



A = Side Adjacent θ
O = Side Opposite θ
H = Hypotenuse

Sine θ = O/H — Tangent θ = O/A — Secant θ = H/A

Cosine θ = A/H — Cotangent θ = A/O — Cosecant θ = H/O

To Be Found

Given	Hyp.	Adj. Side	Opp. Side	Angle	Opp. Angle
Hypotenuse and Adjacent	—	—	$\sqrt{Hyp^2 - Adj^2}$	Cosine $= \frac{Adj}{Hyp}$	Sine $= \frac{Adj}{Hyp}$
Hypotenuse and Opposite	—	$\sqrt{Hyp^2 - Opp^2}$	—	Sine $= \frac{Opp}{Hyp}$	Cosine $= \frac{Opp}{Hyp}$
Hypotenuse and Angle	—	Hyp x Cosine	Hyp x Sine	—	90° − Angle
Adjacent and Opposite	$\sqrt{Adj^2 + Opp^2}$	—	—	—	Cotan $= \frac{Opp}{Adj}$
Adjacent, and Angle	$\frac{Adj}{Cosine}$	—	Adj x Tangent	—	90° − Angle
Opposite and Angle	$\frac{Opp}{Sine}$	Opp x Cotan	—	—	90° − Angle

B.2. ENCODED PROTOCOL TRANSCRIPTS FOR PROFESSIONAL DESIGNERS

B.2.1. JO'S VERBAL PROTOCOL AND DESIGN WORKINGS

00.00.00
(STATING INTENTION) OK. I'm going to first of all I'm just going to read through the ..

00.00.03
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Right. Design an integrated circuit to perform the following computer vision task .. Process an area of RAM memory .. that contains a 2-D TV image ... The chip will be sent two X, Y coordinate pairs ... and constants N, M and 1 ....

00.00.26
(QUESTIONING INVESTIGATOR) So that's .. I can scribble on this sheet as well - there's enough? ..

00.00.33
(READING PROBLEM SPECIFICATION, UNDERSTANDING INPUTS) Input: Sent two X, Y coordinate pairs and constants .. The coordinate pairs, X, Y .. The coordinate pairs X, Y start .. and X, Y end define the position .. Two X, Y coordinate pairs, OK ... Two pairs .. coordinate pairs and constants .. (Unintelligible here) define the position of a line vector drawn over memory.

00.01.02
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) The chip then has to calculate .. N coordinate .. N coordinate pairs along the line vector ... At each ... N coordinate pairs along the line vector. At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given line vector. Using stepping factor 1 .. stepping factor 1 form M .. coordinate pair.. pairs .. Refer to figure 1 below .. At each normal coordinate pair fetch the nearest pixel from memory and summate its value according to the expressions below .. Fetch the nearest pixel from memory and summate its value according to the expression below generating two data items for each normal vector .. These are returned to host ....

00.01.54
(EVALUATING PROGRESS) OK. The first read through I've got the general idea -

00.02.00
(STATING INTENTION) I just need to go into some more specifics now ....

00.02.12
(UNDERSTANDING INPUTS, MAKING NOTES) Inputs: Two X, Y coordinate pairs ....

00.02.20
(EXPLAINING TO INVESTIGATOR) This is normally the way I work. Just draw out the problem ..

00.02.24
(UNDERSTANDING INPUTS, MAKING NOTES) X, Y coordinate pairs, and constants .... N, M .. and 1 ....

00.02.39
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) The chip will be sent two X, Y coordinate pairs and constants N, M and 1. The coordinate pairs X, Y start and X, Y end .... The coordinate pairs X, Y start and X, Y end define the position of a line vector drawn over memory. The chip has to calculate ....

00.03.09
(QUESTIONING SELF) OK .. What is N, M and 1? That's my next problem ...

00.03.15
(READING PROBLEM SPECIFICATION, UNDERSTANDING INPUTS, MAKING NOTES) N coordinate pairs along the line vector .... So N is .. number of .. coordinate pairs .. along line vector .. Coordinate pairs along the line vector ....

00.03.37
(COMMENTING TO INVESTIGATOR) You should measure people's heart rates as well when they're doing this! ....

00.03.46
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS, MAKING NOTES) Coordinate pairs along the line vector .... At each coordinate pair so derived .... So problem one: Generate coordinate pairs .... Generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .... So therefore at each .. new coordinate pair .. you want to generate a normal line vector ... So you want to generate, like that, a normal line vector. At each pair .. generate the appropriate coordinates for a line vector drawn at a normal to the given line vector ... At each coordinate pair .. Using stepping factor 1 .. form M coordinate pairs. Refer to figure 1 below .... No information on 1 .... 2, 3, 4, 5 .... 1, 2, 3, 4, 5, 6, 7, 8 .. N equals number including .. start and end .... M is number of normal coord pairs .. - I'm presuming - I'm going to make an assumption here about your 1 .. <Aha> Uh .. he says 'using stepping factor 1'. Now, there's no information <1 is going along there > OK. But is 1 .. He's got a distance here of 3.

00.06.08
(QUESTIONING INVESTIGATOR, UNDERSTANDING INPUTS) Do I take 1 to be 3, or is it 3 over 1, 2, 3, 4? .. <I think .. I think you have to fill in that information> OK. That's fine. <You have to make some assumptions> Using stepping factor 1 form .. Well I'm presuming because it's a stepping factor, that that's the actual step .. So it's ... 1 is distance between each. OK .... <experimenter prompt> ..

00.06.54
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, MAKING NOTES) Uh, M coordinate pairs. So .. So you want ... M coordinates along the line vector .. Generate .. Vector ... That's the second part of the problem ... First part, second part .. You .. generate ... M .. and 1 spacing .. at normal .. at each normal coordinate pair .. OK .. That's at each normal coordinate pair ..

00.7.41
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, SKETCHING GRAPHICAL MODEL, MAKING NOTES) Fetch .. So you're now working on .. the normal lines ... Fetch the nearest pixel from memory .... On normal lines. At each .. normal ... pair .. nearest pixel .... and summate its value according to the expressions below .. generating ... Fetch the nearest pixel from memory. OK .. So that's like that .. And we're picking out the nearest pixel ... which is .. an 8 bit number .. And summate its value according to the expressions below generating two data items for each .. normal vector .... Through .. that's 5 .. 5. OK .. At each normal coordinate pair fetch the nearest pixel from memory .. and summate its value according to the expressions below ... generating two data items for each normal vector, g(X) and h(X). These are, these are returned to the host .. OK. So it's the output .. in a sense ... k equals 360 over M .. where .. M is the number .. of normal points ... for normal pairs .. xi is the current pixel .. Get a value sine (k times i) .. k is the angle, i equals zero to i equals M ... OK .. At each normal coordinate pair fetch the nearest pixel from memory and summate its value according to the expressions below generating two data items for each normal vector .... Generating two data items for each normal vector, g(X) ... OK. I'm making another slight assumption here again. He said .. uhm. Maybe not, maybe not - I'm generating two data - he said 'generate two data items for each normal vector' .. I'm just wondering - obviously we don't summate over each coordinate pair .. But it doesn't matter, I'll just, I'll just carry on .. OK. Generating two data items for each normal vector, OK. g(X) and h(X) .. I, ah. OK. Sine (k by i) .. So in the .. below case I'd actually generate 1, 2, 3, 4 .. 5, 6, 7, 8 of those, 8 expressions .. and return to the host ....

00.10.58
(STATING INTENTION) I'm going to sort of go into .. uhm - now I think I've understood the problem - just go in and actually again specify the inputs, outputs and internal processing. Just at a very high level.

00.11.10
(EXPLAINING TO INVESTIGATOR) Just to get it clear in my own mind again. I may appear to be repeating myself, but .. what the hell! <Just do as you would normally do> Yeah <Design as naturally as..> Well normally I sit back and spend an hour or two and go to lunch et cetera ..

00.11.26
(READING PROBLEM SPECIFICATION, UNDERSTANDING INPUTS, MAKING NOTES) Uhm .. will be sent two X, Y coordinate pairs ... Inputs: X, Y ... the first input. The second input will be .. X2, Y2. That's giving me a line segment .. And .. (3) .. that's N .. (4) .. M .. (5) .. 1 .. OK. This is ... line vector .. coord's .... N in this case is 8. 1, 2, 3, 4, 5, 6, 7, 8. That's right .. Uh .. That's number of points .. along .. L vector

... (unintelligible here) normal .. form M. This is number of points .. on normal vector ... on normal vector .. And 1 is a stepping factor ... Uhm, 1 ... stepping factor .. for normal .. vector .. OK .... Using stepping factor 1 ..

00.13.11
(EXPLAINING TO INVESTIGATOR) I normally spend quite some time checking through these things ....

00.13.22
(READING PROBLEM SPECIFICATION, UNDERSTANDING INPUTS, MAKING NOTES) 1 is 3 .. M is 5, N is included ... Uh, using stepping factor 1. Refer to figure 1 below .. OK. No information on 1 there. OK ....

00.13.41
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, SKETCHING GRAPHICAL MODEL, MAKING NOTES) Operations .... Operations ... The chip has to calculate N coordinate pairs along a line vector .... (A) .... N .. pairs .. along .. line vector .. So the problem is basically .. having been given an X1, Y1 .. an X2, Y2 ... and N .... - use as the end point, including end points, as I notice from his diagram - .... you are actually going to generate ... N minus two ... new-points ... That's the first task. Second task ... So you're going to actually generate .... uh, X2, Y2, X3, Y3 .. and really that's XN .. giving the suffix one at the start and YN at the end, to generate intermediary points .... At each coordinate so derived. So using .. info' generated in (A), which is .. which is N .. uh, pairs .. - again including N points as we see -.. generate the appropriate coordinates ... for a line drawn at a normal to the given line vector .... So ... at each .. of N points .. generate .... At each, generate M coord pairs .. separated .... by 1 .... Generate M coord pairs. Refer to figure 1 below .. So you've got to generate ... M coordinate pairs separated by N, which is N lines .. ah, normal lines ... got to do ... So that's divided it down into three tasks there .. one task here ... M pairs, separated by 1, on the N lines. OK .... At each normal coordinate pair .. fetch the nearest pixel from memory and summate its value according to the expression below generating two data items for each normal vector .. So for here .. Output. This is really .. uh .. third op' .. plus output .. What you're doing here is ... on a given line .... fetching the nearest pixel .... xi is the current pixel .. So you fetch ... M pixels ... and summate .... by sine and cos ... And you just have your g(X), your h(X) .. Uh, i equals zero to M .. Ah, M is 5, 1, 2, 3, 4, 5 .... zero 1, 2, 3, 4 ....

00.18.03
(UNDERSTANDING INPUTS, READING PROBLEM SPECIFICATION, EXPLAINING TO INVESTIGATOR, MAKING NOTES) Again I'm going to make another assumption here. Mr C----- has given me M equals 5 points as an example, but he wants to sum.. summate over i equals zero to M which is actually 6 points. But not to worry I'll carry on. I think M should possibly have been 4 there, I could be wrong - not to worry .. Zero to M .. nearest pixel .. sine (k times i) .... k is that .. i is just the .. 360 over M, which is the number of points .... Output is N such results ....

00.19.08
(STATING INTENTION) I'm going to have to try and find out how I'm actually going to do this now - these tasks .... Uhm ..

00.19.18
(READING PROBLEM SPECIFICATION) OK. N coordinate pairs along the line vector..

00.19.22
(QUESTIONING SELF) What other info' has he given me here?

00.19.24
(READING PROBLEM SPECIFICATION) .... Uhm .... Uhm ....

00.19.43
(STATING PLAN) Delving into each problem in turn. Looking at it probably from a .. trigonometric point of view .. Uhm ..

00.19.52
(SELECTING SUBPROBLEM) The first problem to solve is the N coordinate pairs along the line vector .. which is problem (A) ...

00.20.04
(SELECTING SUBPROBLEM) Uh, what I need to know .... is the length of the line vector ....

00.20.14
(QUESTIONING SELF) What calculations need to be performed to do that? ....

00.20.21
(STATING INTENTION) Let's see ...

00.20.24
(READING PROBLEM SPECIFICATION) X, Y start .. 8 bits deep, and image array is at least 512 by 512 points ...

00.20.35
(SPECIFYING PERFORMANCE CONSTRAINT, ATTEMPTING TO RECALL) Is there an easy way of doing this? ....

00.20.43
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) N coordinate points. You're given N .... and two coordinates .... Uhm .... It's constant spacing ... Length of the line segment ..

00.21.06
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSION) Just a quick .. quick squiggle. So at a point there which was .. That's X, Y .. which is 1,0 and another point up here which is 3,3 .. So that's 3,3 .. So that's a height 3 and that's a 2 ... So length of a line segment .... is point 3 .. That's distance 3 and 2 .. Uhm, actual length is, uh, root X squared plus Y squared ... X squared equals 4 plus 9 .... Uhm .. Which is root 13. OK, (unintelligible here) find that ....

00.22.03
(STATING INTENTION) Check ..

00.22.07
(PROVING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) Line segment ... X, Y, 3,3, 1,0 .. 3 ... (3 - 1) is 2 .. 3.

00.22.20
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) Ah that's it! .. That's root X squared plus Y squared for that ...

00.22.27
(SPECIFYING PERFORMANCE CONSTRAINTS, EVALUATING MATHEMATICAL SOLUTION CONCEPT) I've got to think of some .. easy formula for calculating the length of the line segment .. I'm sure there must be an easier way. But, however ...

00.22.36
(STATING PLAN) Uhm, I'll just try it for two examples to .. uh .. prove by induction

00.22.43
(PROVING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) .. 1,0 .. and just say for example that's .. 3,3 .. So that a variant 2, and that's a variant 3 .. So using Pythagoras, that's, uh, root 4 plus 9 which is root 13. Now that's the same as having an X1, Y1 which is 3,3, an X2, Y2 which is 1,0 .. Uhm .. subtracting (X1 - X2), (Y1 - Y2) .. (X1 - X2) is 2 .. is 3 .. And it's actually the square root of those two squared - which is 4 plus 9 - That's right! .. Ignoring signs .. Uh, let me just try it one more time. It should be .. Let's see .. Check .. the X coordinate .. 3 .. Yes, (3 - 1).

00.23.45
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) That's right! It's the right formula - has to be! ....

00.23.54
(MAKING NOTES) Uh. Right. So .. X1, Y1, X .. X2, Y2 .. What you've got to do is (X1 - X2) squared - that's the length .. plus (Y1 - Y2) squared .. What shall we call it? - L .. Large L .. Uh. OK ....

00.24.30
(SELECTING SUBPROBLEM) Next thing we've got to have is N points along that line ....

00.24.38
(EVALUATING PROGRESS, SUMMARISING PROGRESS) OK .... Uhm .... OK. I think I've been thrown off a bit by ... OK. That's given me the length. But what I need to know are points on the actual line ...

00.25.17
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) So .... (unintelligible word) axis .. Got to take the angle into account .. Just for argument's sake ..

coordinate point 4,4 .. and this one 0,0 .... Line vector drawn over memory. N coordinate pairs along the line vector .. So we've got 4 .... That's arbitrary .. So N equals 5 .... equals 5 .. 1.. 2, 3, 4, 5 .. (unintelligible here) X and Y points ... The length is that .... Uhm .... OK ... N coordinate pairs along the line vector .... 8 bits deep .... Can't remember any bloody trigonometry .... Uh .... N equals 5. First point .. Take two X, Y .. N coordinate pairs .. over the line vector .. M and 1 .. drawn at a normal. OK .. So we know the length of the line vector .... Uhm .... we could calculate that .... Aha! .... That's OK ... Knowing the length .. we can, ah ... and the number of points - which is 5 .. 1, 2, 3, 4 - we can divide the length .. over .. 2, 3, 4, over (N - 1) ... given P----'s .. N equals 8 .. 1, 2, 3, 4, 5 .. 8 there ...

00.28.16
(SUMMARISING PROGRESS, EVALUATING MATHEMATICAL SOLUTION CONCEPT) So we know the distance .. as the crow flies between each point .. Uh .. But what are? .. Now the X, Y coordinates ... Just call it X .. So knowing X we want to find these two points .... Should be easy .... Ah, I see there's an iterative formula coming out here ... (unintelligible here), uhm .. distance .. X ... 2 root (unintelligible here) .. and the final point .... be on the same slope .... (unintelligible here) .... <experimenter prompt> Yes. OK .. Yes, no problem .. 3, 4 .. coordinates on the bottom ... and along the top .. We will actually work .. So we're getting in to all these angles and .. rubbish .... If we just take the bottom, that's 4 .. this is 4 .. divided by (N - 1) gives me 1 .. Ah, aha! .. OK ...

00.30.20
(STATING INTENTION) Let's try this one more time .. To find N coordinates along the line ..

00.30.29
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICICAL EXPRESSIONS) Let's take for example .. again 0,0, 4,4 .. Uh, that is 4 .. so N equals 5 .. So I need 1, 2, 3, 4, 5 points .. So that's 4 ..

00.30.45
(EXPLAINING TO INVESTIGATOR) Just sort of using a simple example to prove again .. that what I'm talking about is not absolute rubbish ..

00.30.51
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) Uhm .. 4 coordinates along the line - they should be just split obviously equally .. So .. uhm .. This distance .. So let's call that X1, Y1, X2, Y2 .. and this distance here is (X2 - X1) .. and this distance here is (Y2 - Y1) .. and if I divide that by .... (N - 1) .... we get a stepping distance ....

00.31.36
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) Yes! .. So I have a formula .... Coming across to a formula to find these N coordinate points .. There's no real need, I don't think, for any fancy trigonometry ... Uhm

...

00.31.54
(STATING INTENTION) Let's look along the bottom ....

00.31.58
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) OK. Given X1, Y1 at the start, we've derived some sort of reasonable formula .. X2, Y2 .. equals 5 .. What do we do? .... We want to find an X step .. and a Y step ..

00.32.18
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) The X .. step is (X2 - X1) over (N - 1) .. Y step .. equals (Y2 - Y1) over (N - 1) .... and .. OK .... First point ...

00.32.41
(STATING INTENTION) Let's just prove this .. on the side here ..

00.32.47
(PROVING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) X2 is 4 .. minus 0 over 4 .. Pretty simple example .. 4 equals 1 .. equals 1 ..

The first point is X1, Y1 .. 2nd, 3rd, 4th, 5th obviously has to be X2, Y2 .. That's X1 plus ... (X2 - X1) over (N - 1) ... That's the X .. and the Y1 plus (Y2 - Y1) over (N - 1) .. and that's actually an iterative formula ..

00.33.33
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS, MAKING NOTES) That.. that I know will come down to some sort of accumulate function .. That's thinking about it in hardware .... That's quite easy in fact ... Now I'm presuming .. that this idea is going to work ..

00.33.50
(STATING INTENTION) I'll try it through a simple example ..

00.33.53
(COMMENTING TO INVESTIGATOR) I find myself talking through it - it's almost as if I'm talking to an audience. I don't know .. It's not normally do I think aloud .. It's just when you. Normally I would not verbalise, in normal situations ..

00.34.05
(QUESTIONING INVESTIGATOR) OK. How much time have I got .. Three quarters of an hour left. OK ..

00.34.31
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) So that's the accumulate function .. X1, X2 .. So the first step really using our 2 points .. That's the key calculation there ... That .. I presume it must work for

any other .. uh ..

00.35.03
(PROVING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) Let's just quickly try .. another 0,0 point, but say a 3,2 .... and put .. N equals 5 again .. 2, 3, 4, 5 ... Uh, the first X step is X2 .. which is (3 - 0) over 4 .. equals 3 over 4 .. X step .. Y step is .. (2 - 0) over 4, which is a half .. So the first step is 0,0 then it's a half, then it's 3 over 4 ... 1.5 .. 2.25 .. 3 .. 1, 2, 3, 4, 5.

00.35.51
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) That's right. So that's the first formula .. OK. That should be pretty easy to do ....

00.36.05
(EXPLAINING TO INVESTIGATOR) I'm normally just going through the mathematics first - to check that I can actually do this thing ..

00.36.12
(SELECTING SUBPROBLEM, MAKING NOTES) Right .. this is (B) really - which is the second problem .... Uhm ...

00.36.24
(SUMMARISING PROGRESS, MAKING NOTES) So I've now got my .. N ... coordinate pairs .. along .. line segment ...

00.36.37
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) Generate the appropriate coordinates for a line vector drawn at a normal .. OK. I've got M pairs, at each N point, M coordinate pairs separated by 1 ... aligned at the normal ....

00.36.51
(SELECTING SUBPROBLEM) Ah. Right. Firstly ... given the coordinate, I need to generate ... normal values ...

00.37.04
(UNDERSTANDING INPUTS, MAKING NOTES) Got M is the number of points .. 1 is spacing ..

00.37.10
(EVALUATING PROGRESS) OK. This should be pretty ... straight forward ....

00.37.19
(SKETCHING GRAPHICAL MODEL) X, Y .... and .. at right angles to that ...

00.37.30
(QUESTIONING INVESTIGATOR) Are you more interested in the hardware at the end or in how someone solves these higher level problems? .. <The higher level..>

00.37.35
(EXPLAINING TO INVESTIGATOR) OK .. Yeah ... 'cos I mean I could sort of

on a few hunches blast into drawing out block diagrams .. but I would normally prefer to solve all of the .. you know, the mathematical problems at the top level first <Uhm .. I don't mind if you do block diagrams .. I'd quite like you to pursue your ideas some way> .. OK .. Fair enough ..

00.38.02
(ATTEMPTING TO RECALL) X, Y .. Find a point ... Trying to remember some geometry .... Uhm ...

00.38.15
(STATING INTENTION) See if he's left me any clues ..

00.38.17
(GENERATING MATHEMATICAL SOLUTION CONCEPT) No .. OK .... I can work on slopes - but, uh. Yes I need the slope .... I need the slope of the line .. That's what we have in reality ..

00.38.39
(STATING INTENTION) Just try an example ...

00.38.43
(PROVING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) Uh ... So that's 0,0 and that's 3,3 .. Just for arguments sake .. That's 1,1 .... and have another point there, 2 .. 2,2 .. 3,3 ... M points along the coordinate .. Now you know X, Y .... Uhm, what the bloody hell is the slope of a line again! .... This angle .... Let's see .... We need to know that slope .... Let's see. (Y2 - Y1) .... Slope equals (Y2 - Y1) .. (X2 - X1) .. So if I try it in this case .. minus Y1 is minus 0 .. over ... minus 0, which is 1 .. which is tan to the -1 of .. 45 degrees .... So if I had .. point .. 1,1 on a line .. and I wanted to make that .... what would be my next point? .... (unintelligible here) .. 1,1 .... ah .... 45 .... minus Y1, M (X - X1) .... That's 45 .... normal to a line vector .. That point, that point, that point and that point .... Uhm .... Slope of the line .... Y equals MX .. (MX - .. N) ... (unintelligible here) .. I have 90 degrees ...

00.41.59
(STATING INTENTION) Let's just .... try this one ..

00.42.05
(PROVING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) 0,0, 0,1 ... (Y - Y1) .. (Y2 - Y1) .. (Y - Y1) is that over that is tan of the angle .. That over that .. is 1 over 0, is infinity .. Right .. That's 90 degrees .... that's the slope .. 45 .. tan of angle ... Should really use tan .... That's the slope .. 45 plus something else ... Uhm .. we now that's 90 degrees .. on top of that one .. Ah, add the slopes together, you get an angle of 45 degrees .. plus 90 .. What slope do you have for that? ... That one's 1 .. and in fact .... Yeah. OK. So that's 90 over .. That's about 45 .. In fact now I'm out here with 90 degrees .. So that's 45, so in fact I think I might just have to negate signs here .. of the current slope .. That one's going out to 3,3 .. So this one should go out to .. Ah, -3,0, -3,3 ... Uhm .... going out to -3,3 by negating the top component .. So what have I down there, uh, 45 .. uh .. 3,0 .. to -3,3 ... Change the sign by

knowing 45 degrees that of the slope .. 1 ... I have .... equals MX plus ... (Y - Y1) over (X2 - X1) equals M .. to (X2 - X1) .. Try this one. This is Y .. minus .. minus .... (Y2 - Y1) .. plus M which is, uh, Y2, which is (3 - 0), equals M .. to X2, (3 - 0) .. minus Y1, equals (unintelligible here) (Y - 3), equals ... (unintelligible here) is 3, equals (X - 3) plus 3, Y equals X .. In the other case you have .... (unintelligible here) .. Y equals -X + 3 ..

00.42.25
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) That's incorrect .. Y equals -X .... Getting a bit stuck on this one here .... The slope .... Uhm .... OK .... So that point ... We shove it over 90 degrees .. Whatever (unintelligible here) its 90 degrees .... There's something .. There's a message in there about the slope .... So if Y equals -X .... then .. Y equals 1 ... that's -X .. X equals 1 .. equals -1 .. so -Y equals X .. and X equals -1 .. Y equals 1 .. That's right .. I just change the slope .. Negate the slope .. to have 90 degrees .. OK ....

00.47.05
(STATING INTENTION) Try that again ....

00.47.12
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) That's the slope of the line .. That's minus the slope .. So .. slope (unintelligible here) ... Y equals X ..and Y equals -X .... minus 1 .. Y equals 1, X equals 1, Y equals -1 ..

00.47.57
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) That's what we want!....

00.48.00
(STATING INTENTION) OK. Let's ... get a bit more ... Derive a formula for this ....

00.48.09
(GENERATING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) This is 3,3 .. Uhm .... What we now want are points on this line .. at the appropriate .. Separate into stages .. OK .... Knowing the coordinate point .... and ... knowing the slope ... to negate the slope, we have .. I think we have to calculate the slope ... Steps of 1 .... M pair number of points and 1 spacing ... Uhm ... OK ... We can actually calculate the slope .. before .. from X1, Y1, X2 and Y2 .. Do this in parallel as the .. as the data actually comes in .. And the slope equals (Y2 - Y1) over (X2 - X1) .. let's say tan to the -1 of the angle ... which I normally call M ... Right .. And I know .. one point .. on each line ... So now I'm going to have to do the formula .. I know (Y - Y1) equals M (X - X1). So now M equals -M because of a 90 degree line ... So we could in mathematics derive an equation .. for a line ... But .... uh, (X - M) .. But really .. (unintelligible here) will be practical .. Uhm .... uh. So .. if I have a point .. If I negate the slope of something .. multiply it by -1 ..

00.50.31
(STATING INTENTION) Just for argument's sake, I'll just try here ..

00.50.34
(PROVING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) If that's 1,1 .. 2,2 ... and if I put that up there .... and I put a spacing up here .... 2,2, 3,3 .... (L ... uhm ... - M) .... negate the X coordinate ..

00.51.08
(STATING INTENTION) Try that one ....

00.51.13
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) Before I had a point, 1,1 .. On the next spacing I step .. X step, Y step ... which was, say, three quarters, and a half ... which was 1.75 ... three quarters, and a half ... If I negated the X step ... Y equals -X .... Y is (unintelligible here) my X is starting negative .... If I came down like that .... I should go back .. and subtract the X step from that .. subtract X step ... I think that could be it ..

00.52.24
(STATING INTENTION) I'll just quickly try that one ....

00.52.29
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) So out of all this messing about with formulas I can actually .. If I .. I can calculate the X step and Y step .. If I now .. keep my Y step. That would keep my .. the things going up in the right way ... But now I want to just subtract the X step from it .... to go back by 1 ....

00.52.58
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) If I had a line up there, 0,0 3,3 .. 2 and this is 1,1 .. 1 2,2 .. and my end points were .. That's an X step there .. (3 - 0) over 1, 2, 3 .. So that's 1, (3 - 0) over 3 equals 1 .... 0,0 1,1 2,2 3,3 .. And just say our spacing .... at point 1,1 .. And that was at 90 degrees .... And .... (unintelligible here) .... slope of the line .... minus the tan of the slope .... Uhm .... points on a line .... <experimenter prompt> .. Yes I'm starting again .. I'll start again .. Ah, Y minus 1 equals -1 to X minus 1 .. slope of -1 going through 1,1 .. (Y - 1) equals (-X + 1) .. Y equals -X .. plus 2 .. Actually use (-X + 2) .... Uhm. What's that telling us about it? .. It's the same equation of the line, but it's plus 2, which is plus the coordinate on that .. So it's actually adding those together .. adding the X1 and Y1 together into the line .. Uhm. So if I put X equals 0 .. X ... equals 0 .. Y equals 2 .. 0 .. equals 2 ..

00.56.46
(QUESTIONING SELF) Does that actually work properly? ..

00.56.49
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) So Y equals .. X equals 0, Y equals 2 .. So 0,2 1,1 .. Y equals 0, X equals 2 ... X equals 2, so the step there .. If I had 1,1 then that does go through 2,0 .. so 2, the step is 1 .. 1,1 .. If I add .. the slope of the line is -1, step .... If I ..

add X step .. subtract Y step .. Right. OK .... X step and Y step .... X step.

00.57.58
(EVALUATING MATHEMATICAL SOLUTION) So just add and subtract .. That's exactly what it is.

00.58.02
(STATING INTENTION) So just check that once again ..

00.58.04
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) 1,1, so Y equals -X plus 2 ... X is 0, Y equals 2, so that's 0,2, Y equals 0 minus X .. X equals 2, 2,0 .. I have 1,1 and my step was 1,1 .. So these lines you ... add X step .. subtract Y step .. That's 1,1 .. which is .. plus .. Y step ... And the other direction you subtract .. X step ... add Y step. OK .... So really, uh, now .. uh, using stepping factor 1 .. Right, using stepping factor 1 .. So if now we have point .. on line .. X1, Y1 ..

00.59.18
(EVALUATING PROGRESS) It's a pretty long proof this. But, however .. Uhm ..

00.59.23
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) For points on the line .. So this is X1, Y1 .. 1 equals ... step factor .... and you want M points. M he says 5 .. So you want ... 2 .... This is .... step factor ... That far up .... Uhm .. The step factor is that one .... Minus step factor 1. OK. The step factor is .. coming into it a little bit .. X1, Y1 .. plus X step .. plus Y step ... Stepping factor ... is 1 ... Move the point up .. that bit .. The distance 1 ... uh, say 1 equals .. 2 ....

01.00.54
(EVALUATING PROGRESS) Ah .... OK ... I've screwed this up a bit ....

01.01.11
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) OK .... Form M coordinate pairs using stepping factor 1 .. M coordinate pairs .. So let's just say if it actually was 1,1, and say 1 equals a half .. 1 equals a half .. We wanted to find. We needed that line. So Y equals (-X + 2) ... And we wanted to go up by half .... to go up by half .. and at an angle of that .. We know the slope .... (unintelligible here)

01.02.16
(ATTEMPTING TO RECALL, EVALUATING MATHEMATICAL SOLUTION CONCEPT, SPECIFYING PERFORMANCE CONSTRAINT) .... That's .... Uhm ....There's a simpler formula for these bloody points on a line but I can't remember! ....

01.02.51
(STATING INTENTION) I'll have to look at that one again ....

01.03.18
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) That point we wanted a stepping factor .. to look a little bit like that .... Adding 1 ... Uhm .... (X + 2) ... Y equals 0 .. X equals .. 2 .. X equals 0, Y equals 2 .. and that .. X equals 1 .. Y equals 1 ... Stepping point 1 .. So it's minus that slope .... That's 90 degrees .. So at the point 1 .. in that direction ... (unintelligible here) ... Say there's a point 1, say 1 equals a half .. And I have a point 1,1 .. Now put point .. And I said ... subtract X step .. (unintelligible here) .... That's a half up that way .. and half .. 1.5 .. which would be ... (unintelligible here) ... 1 .... And that point there .... That point up there .. Subtracting (unintelligible here) I've moved a half back in this direction ... Which is not right .... From that point to another .... That's related to the movement here .... (unintelligible here) .... That's X step .... (X2 - X1) .. 1 .. (unintelligible here) .. Accumulate function .... (unintelligible here) ... So it's the same thing ... I predict a line .. got 1 .... That's the length of it ... We have one point on a line .... Uhm ....

01.07.02
(EVALUATING PROGRESS, COMMENTING TO INVESTIGATOR) Getting bogged down with the geometry here. But, however .... We're possibly going to run over the time .. <That's all right, keep going> .. OK. No problem ..

01.07.32
(PROVING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) 1 over 2 .... Just transferring the coordinates through 90 degrees .. At that one line you step ... M coordinate pairs ... So we really need to divide it into .. M here is 5 so it's over 4 ... And the distance is 1 .... 4 points, 4 segments ... And the distance is 1 .. 1 .. That's 1 .. 4 of these distances .. The X step and Y step .. (X2 - X1) .. over (M - 1) .. step in this direction ... that's (X2 - X1) over (M - 1) .. now we want .. the distance between .. the right hand triangle .. which is minus the slope .... uhm .... which is minus the slope ..

01.08.54
(STATING INTENTION) Let's just review a bit ....

01.09.02
(PROVING MATHEMATICAL SOLUTION CONCEPT) Along the given line vector .. (X2 - X1) over (M - 1) .. (M - 1) .... That's an accumulate function .. Right, the second problem. Step through along these points ... N coordinate points (unintelligible here) ... That's 1 .. That's the slope for 1 .. So that's minus the slope .. 90 degrees ... That's minus slope ... Could go brute force and ignorance .... Spacing 1 .... Spacing 1 .... Uhm. OK. Just (unintelligible here) .... that spacing .. in this direction .. it's .... (unintelligible here) line .. at a point ... Taking X1 and Y1 ... So 1 equals 1 .. Uhm ....

01.11.07
(GENERATING MATHEMATICAL SOLUTION CONCEPT, MAKING NOTES, SKETCHING GRAPHICAL MODEL) OK. I could approach this in a very crude ... crude way instead of trying to do something clever ... Y step .... M points .. Spacing 1 .. All at a normal ... So ... we have the slope ... of the

first line .. plus point on a line .... New slope ... equals minus first slope .. Spacing 1 .... 1 form M coordinate pairs, using stepping factor 1 ... Stepping factor 1 ... Stepping factor 1 .... That's 1 .... using stepping factor 1 .. Right ....

01.12.24
(QUESTIONING SELF) Do we know much about the step?

01.12.30
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) .... (unintelligible here) triangle, that's 1 .... Point on a line .... Point X1, Y1 .. Slope M ..

01.13.19
(EVALUATING PROGRESS, GENERATING MATHEMATICAL SOLUTION CONCEPT) Oh! .. X, Y direction .. Ah! I might have made a .. an assumption here. I'm now going to assume he hasn't said anything about 1 but it's a step in the X and Y direction .. Up to now I think I've been sort of going around in a circle a little bit .. Uh. So I'm going to carry on with that assumption .. Yeah .. 1 .. step in X and Y direction. So if we've got a point .... So we just subtract the 1. That's right .. So .. we've got the points X1 and Y1 .. And there's them on a line .. Ah. We just negate the slope .. So ..

01.14.11
(EXPLAINING TO INVESTIGATOR) Yeah. I've been assuming to date that the 1 was actually .. a vector step. But I presume - as it's not stated there - that it's done in both the X and Y direction .. I was trying to derive a formula that would give me the sine and cosine of 1 to add onto it ... Anyway ..

01.14.28
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) So given points X1 and Y1 .. I just go back to my .. top one which was subtract from the X .. these ones .. and the 1 is (X1 - 1) .. X, uh, (Y1 + 1) .. And the opposite down here ...that's a step in direction for X and Y .. Christ! (unintelligible here) .... ridiculous! .... That's an angle of 45 degrees. That's right (X .. - 1) .. that's a half ... and, uh, Y plus.. (Y1 + 1) ... if you're moving in this direction, (X - 1), (Y + 1) ...

01.15.25
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) That's the formula! .... OK. That's the first one ..

01.15.32
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS) The second one .. (X + 1) .. So you subtract .. the 1 from the X coordinate .. And it's up .. So on the way down here it's M equals 0 .. It changes .. It's, uh, (X1 + 1) ... And the Y is .. on the way down .. (Y1 - 1) .. And the root is actually the point, your X1, Y1 coordinate .. and so it stays on the line ....

01.16.00
(SELECTING SUBPROBLEM, READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) Right .. At each normal coordinate fetch the nearest pixel from memory .... Coordinate .. At each normal coordinate pair fetch the nearest pixel from memory .... So it's the third, it's the (C) option .. We want to fetch the nearest pixel .. from memory .. and summate it's value according to the expressions below generating two data items .... Pair g(X) is xi .. Pixel .... k equals 360 over M L

01.16.50
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT) Look up table ..

01.16.53
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) And were's going to have a sine .... k.i .... returned to host ... Each normal .. So it generates (unintelligible here) .. to generate normal coordinate pairs here ... M and N and spacing 1 .. That's spacing 1 .. Now fetch the nearest pixel from memory .... The nearest pixel .. I interpret that as just taking the, uh. We can truncate around .. a number .. Uhm ... And also we're just sending the address out .... Fetch the nearest pixel from memory .. So that's the second .. And summate it's value according to the expressions below to (unintelligible here) .... That's a pixel .. That is a sine. That's a multiply .. That's an accumulate ...

01.18.10
(EVALUATING PROGRESS) OK. So I've got the first batch of processing coming along ..

01.18.14
(COMMENTING TO INVESTIGATOR) I'm probably going to be about an extra quarter of an hour, twenty minutes <Yes, that's fine>

01.18.17
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, WRITING MATHEMATICAL EXPRESSION) OK ... generate two data items for each normal vector, g(X) and h(X). These are returned .. to the host .. That's a pixel .. to M .. Returned to the host. OK. 360 over M ... uhm .... 360 over M ..

01.18.43
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, GENERATING ABSTRACT HARDWARE CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, MAKING NOTES) Just make that a look up table .. (unintelligible here) .. OK .... (C) is .. you take, uh .... normal .. pair .... At each coordinate pair .. you want to fetch the nearest pixel. So you'd put that into some sort of rounding to actually get integer .. values .. But you could end up with fractional up here .. Rounding up here .. Integer values .. And .. you send out an address ... X, Y coordinates .. So presumably you've got some sort of X, Y addressing .. Send two coordinate pairs. OK .. At each normal coordinate pair fetch the nearest pixel from memory .... And rounding ensures the two make up an address .... Address out .. Take data in ... In, and then ... what you actually have.

01.20.00
(STATING INTENTION) Let's just draw a quick ..

01.20.02
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, SKETCHING GRAPHICAL MODEL, MAKING NOTES) You've got a Multiplier .. and you've got an Accumulator .. which ... xi .. MUX .. is the pixel coming in .. And this side ... xi and sine i ... Add ... Multiplier. Sorry .. It's going in like that .. xi. sine (k times i) .. k equals 360 over M .. Now .... if you have .. a 512 by 512 screen .. uhm ..... 512 screen .. M .. M coordinate pairs .... the biggest number of coordinate pairs along the diagonal .... which I'm just going to do a quick calculation - say it's root 512 squared plus 512 .. What I'm really just calculating is the number of .. Oh, Christ, hang on! I haven't got a calculator .. Well, OK. I'll just leave the calc' like that .. What I'm actually calculating there is, uhm .. I want to know I'm not going to use anything. I'm just going to use a ROM and a look up table for sine and cos ..

01.21.34
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SPECIFYING PERFORMANCE CONSTRAINTS) It's much more easier .. Easier to change, and more eff.. not necessarily more efficient .. but it's a bit better .. But I need to know how many values to store in the ROM .. And I know that it's 360 over M .. and M .. uh .. M coordinate pairs on the normal vector .. The largest you could have .. is a diagonal .. So that's the number of Ms ... OK. That's a silly problem ... I'm getting more into the hardware now ...

01.22.04
(STATING INTENTION) I'll see what it says.

01.22.05
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Return to the host. So that's output.. output .. input.

01.22.07
(STATING INTENTION) So let's .. let's just go through a quick .. just a quick block diagram of what's happening here ...

01.22.20
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Uh, X, Y coordinates .. Represent two X, Y coordinate pairs .. So input .. that's just N .... M ... 1 .... Right, OK. I'll (unintelligible here) X and Y at the moment - they could obviously come in on the same bus, but we're not .. too concerned about that at the moment .... N coordinate pairs along the vector line ... And out here .... going to address the (unintelligible here) .... That's data .. IN .. This is add .. X add .. Y address out .. This is actually going to happen here .. because .. Fetch the nearest pixel from memory and summate its value .. And this is going to pull data in again ....

01.23.25
(QUESTIONING SELF) So what are the first operations it's going to perform? ...

01.23.29
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, WRITING MATHEMATICAL EXPRESSIONS) Let's have a little store in here anyway .. It's going to have X1 .. Y1 ... Let's just (unintelligible here) .. and so it's going to get first .. XN and YN I'll call them .. They're two .. And it's obviously going to hold a little store here of these values .. N, M, 1 ... Crude diagrams .. Now, the first thing we generated was this function ... storage points .. uhm, was (XN - X1) over (N - 1) ... N .. so we've have the block function here .. uh ... we've got a Subtractor ... should add/subtract really ... and that will .. come down here .. that will generate values like .. (XN - X1), (YN - .. Y1) ... Ah, right, and then we go into a Divider .. and this will take .. N - or really it's (N - 1) but not to worry .. we do shifting etc .. right .. OK. That generates our step .. for X and Y .. Uhm .. for X and Y .. Uhm .. Right, going over ... I need an accumulate function .. So the first point we have .. the X and Y ... So you just add it together .. the step for X and Y .... Down here you need some sort of Adder .. X ... step .. And we could have .. Y .. That's X1, Y1 plus step .. plus y step .. That's X, Y step, some storage .. here .. So X step plus Y step .. Just an Adder there and an Adder there to calculate that .. And the (unintelligible here) coordinate points .. Let's extend this down here .. Step ... Going to be a MUX there .. which will feed that back round .. MUX, feed it back round .. And these will actually go to storage down there, the coord points .. which is N of them .... Now you could treat this as a .... ah, OK ..

01.26.40
(EXPLAINING TO INVESTIGATOR) We're used to dealing in sort of parallel data flow architectures, so I'm just going to try out all the hardware - I do appreciate that you could actually loop back around in here, but that's for a later date .. Uhm ..

01.26.54
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, WRITING MATHEMATICAL EXPRESSIONS) Let's see, the next point we've got to do is taking each of these .. coordinates in turn .. and it's just an (X + 1), X .... OK ... so you take a coord point ... and ... it's ah .. (X + 1), X .. uh, (X + or - 1), (Y + or - 1) .. uhm .. again that's ... iterative .... and that generates your normal points ... You put these .. and you truncate around .. and that goes up to the X, Y address .. sends data in - pulls the data in .. and .. this is very very crude now .. new data coming in .. you've got your, uh, sine look up .. now .... look up table ... uhm .. which is going into a Multiplier .. coming out to an Adder .. You could actually do these in parallel .. That, that, that .. around like that .. And these are returned to the host .. They're actually output .. That's the first cut ..

01.28.46
(STATING INTENTION) We can get a bit more specific now ..

01.28.55
(STATING PLAN) Probably go through this about .. Well I don't have much time left. But ....

01.29.02
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, WRITING MATHEMATICAL EXPRESSIONS) Draw the input, data in .... X .. Y ... N .... 1 .... OK .... Storage .... do coordinate points ... X1, Y1 .. XN, YN ... OK ... To do the X step and Y step calc's .... OK. (unintelligible here) .. register files at the top ... another register file .. down here .. The first thing we do .. to calculate the stepping functions .... ah, which is add (X2 - X1) ... Subtract .... Uhm .. This is a plus/minus ... Uhm .. What you actually have up here is ... 2, 3, 4 .. Which comes out like that ... Ah, this - just writing up the side - generates the .. (XN - X1), (YN - Y1) .... Uhm .... Uh. Divider .. function N .... yes, it's actually dividing (N - 1) .. probably use this .... generates (N - 1) as well .. Now .... Uh, probably a bit more storage there ... (XN - X1), (YN - Y1), (N - 1).... Uh, and down here we perform two divisions. Now these again ... The Shift .. OK. This is Divider/Shift .. and it's .. uh, it's a Divider and Shift. Right .... This is X step .. Y step .. and .. just for completeness ... storing there .. X step and Y step functions .. Now .... what we can do is ... I could actually loop back there ... and use the same Adder .. It depends if you want to optimise hardware or not - I could actually use the same Adder to perform .. But for the .. Just for the hell of it I'll actually ... X step .. I'll actually, uh .. just use the normal ones .. And you could of course calculate these in parallel ... So let's do it .. plus/minus ... I think they're just Adders anyway .. and fed in from here from the top .. are X1, Y1 ... ah, X step .. generating X, Y .. to storage .. these are, uh.. N .... and you'd actually store the N coordinate pairs in there .. Now .. next part of the hardware .. Uhm .. Coordinate pairs. You feed .. This is a bus .. You feed these coordinate pairs ... Once again you could .. I'm doing a sort of pipeline architecture here, but you could again double back ..

01.34.42
(SPECIFYING RESOURCE USAGE CONSTRAINTS) I've now put down a lot of resources .. You'd have to check if you can use them in parallel or not ..

01.34.47
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Uh. Store N points .. Uh. This is really .. Drawing that as a bus .. This is X, Y .. and here we have our stepping functions, X minus .. This is a .. This is a .. That's into .. plus/minus ..

01.35.11
(COMMENTING TO INVESTIGATOR) I won't be too much longer Linden ..

01.35.15
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, MAKING

NOTES) Uh, X minus Y function ... Uhm .. And th this has got 1 ... X .. And this has got .. This is the add/sub .... normal coord's .. normal coordinate pairs. OK ... These are normal coordinate pairs and we store them here .. Uhm. Right ... Next ... This is M .. OK ... Fetch the nearest pixel from memory at each normal coordinate pair .. this .. these go out into rounding .. slash truncate .. and ... I presume both together for a single address .... Address out. OK .... That's the address out from the rounding and truncate circuitry, to send it back round .. Now .... when the X,Y come in again ... OK. Now again .. I'm not utilising the pipeline - I'm just drawing this out very quickly - aspect of this .. you want to perform a, uh, multiplication and accumulation. So .. got a multiplier .. Second multiplier .. Always accumulate - Yes? - Add .. Add .. Accumulate .. Accumulate .. Running out of space .. And these are returned to the host .. Output .. Output .. Outputs, uhm .. that's g(X), h(X) .. Address out .. Now in here .. These are generated. These are fed .. to the sin and cosine at the same time .. sine and cosine at the same time .. OK .... So it's, uh, g(X) which is sine .. and this is cosine .. Uh. You need ROM .. You're doing sine .. Yes you can actually split your ROM into two there - cosine and sine - this is a .. sine ROM .. but by clever address generation .. you can get .. the same stuff out .. The size of this ROM is ... Assuming you're operating 8 bit pixels.. is root 521 squared plus 512 squared ... times 8 bits .. That's because M .. can be .. uh, as big as a diagonal .... Uhm .... OK .. Control .. Address generation. You need a Sequencer and Controller. Basically it's a pipelined engine .. uh, with control ... and store .. and you can see the data flow down through .. Generating it ... Address out and data comes back in and around again .. Uhm .. Put down here .. for fully pipelined .. you'd probably have 4 input, 4 data input ports ... uh, so that .. could take .. in, uhm .. raw pixel .. OK. Could take in raw pixel .. and the, uh, newly, uh, truncated at the same time. So I'll just put up here a note .. Duplicate .. for full pipeline ..

01.40.54
(COMMENTING TO INVESTIGATOR) OK .. OK, Linden .. I can't really go much further .. I could do and draw bit sizes and that, but ....

01.41.08

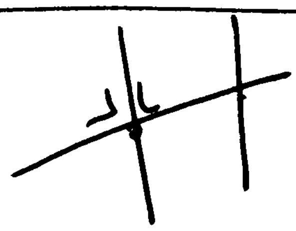
INPUTS

TWO X,Y CO-ORD PAIRS

CONSTS: N, M, L

1) N: no of co-ordinate pairs along line vector. (Gen co-ord pairs)

At each new co-ord pair.



2)

N = no including start + end

M no of ⊥ co-ord pairs

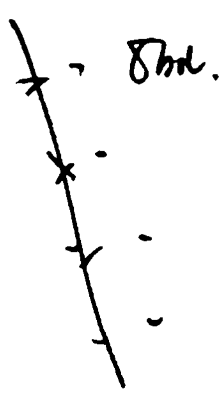
L :

} Generate. M, L spacing ⊥

---

3) ON NORMAL LINES.

AT EACH NORMAL – PAIR. – NEAREST PIXEL



2

INPUTS:

① X_1Y_1 ② X_2Y_2 ③ N ④ M ⑤ L

① and ② (together): Line vector co-ords

③ N: NO OF POINTS ALONG L VECTOR

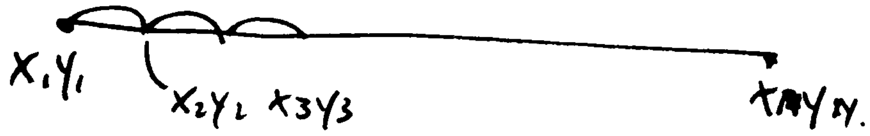
④ M: NO OF PTS ON NORMAL VECTOR

⑤ L: STEPPING FACTOR NORMAL VECTOR

OPERATIONS

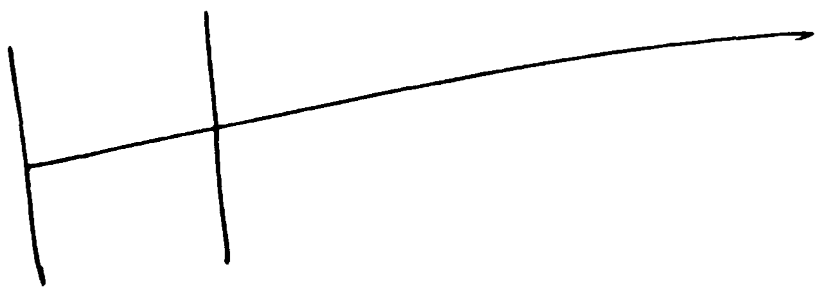
Ⓐ N CO-ORD PAIRS ALONG LINE VECTOR

N pairs (including end pts) (N-2 - new pairs).

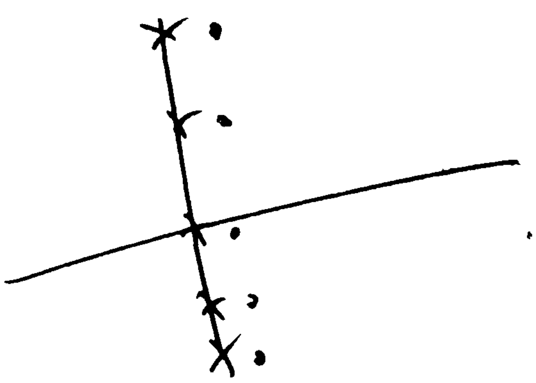


Ⓑ USING INFO Ⓐ = N pairs.

AT EACH OF N PAIRS GENERATE ① M CO-ORD PAIRS
② SEPARATED BY L.
③ N LINES (NORMAL)



Ⓒ 3rd OP + OUTPUT.



FETCH. M PIXELS

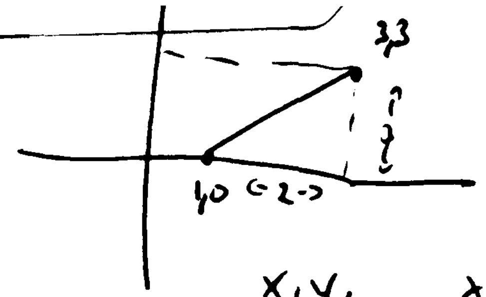
$\frac{360}{M}$

$g(x)$ $\sum_{i=0}^{M} x_i \sin(k.i)$

$h(x)$ $\sum_{i=0}^{M}$

op N such Results.

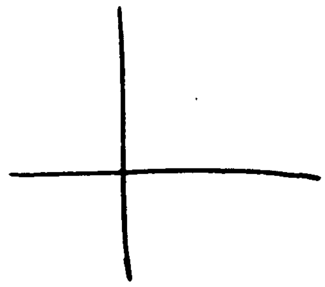
(A)



$\sqrt{4+9} = \sqrt{13}$

$x_1 y_1$	$x_2 y_2$	$x_1 - x_2$	$y_1 - y_2$
3,3	1,0.	2	3.

$\sqrt{4+9}$ = ✓.

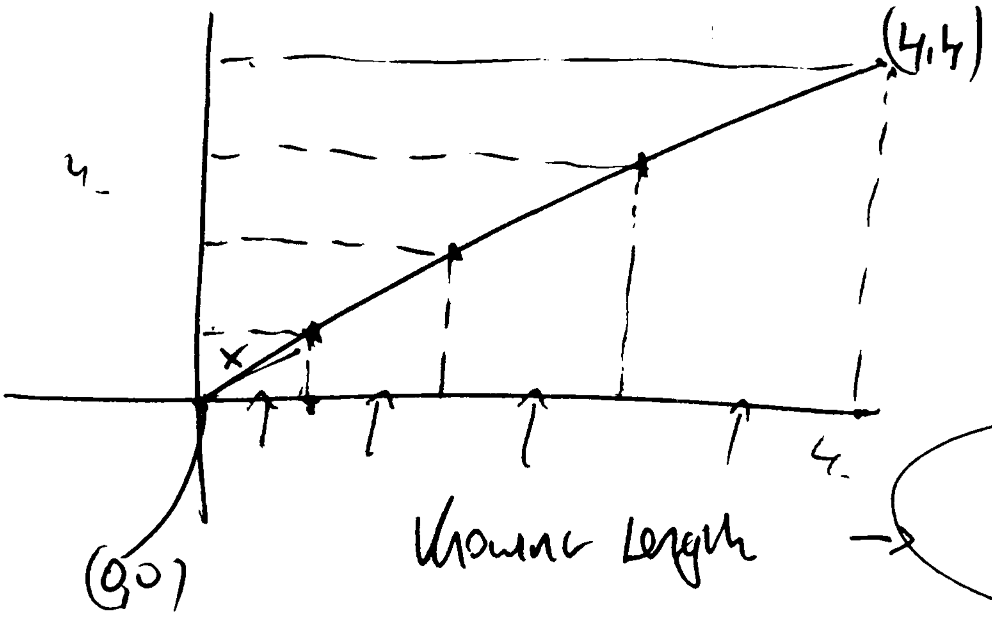


$x_1 y_1$

$x_2 y_2$

$$L = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

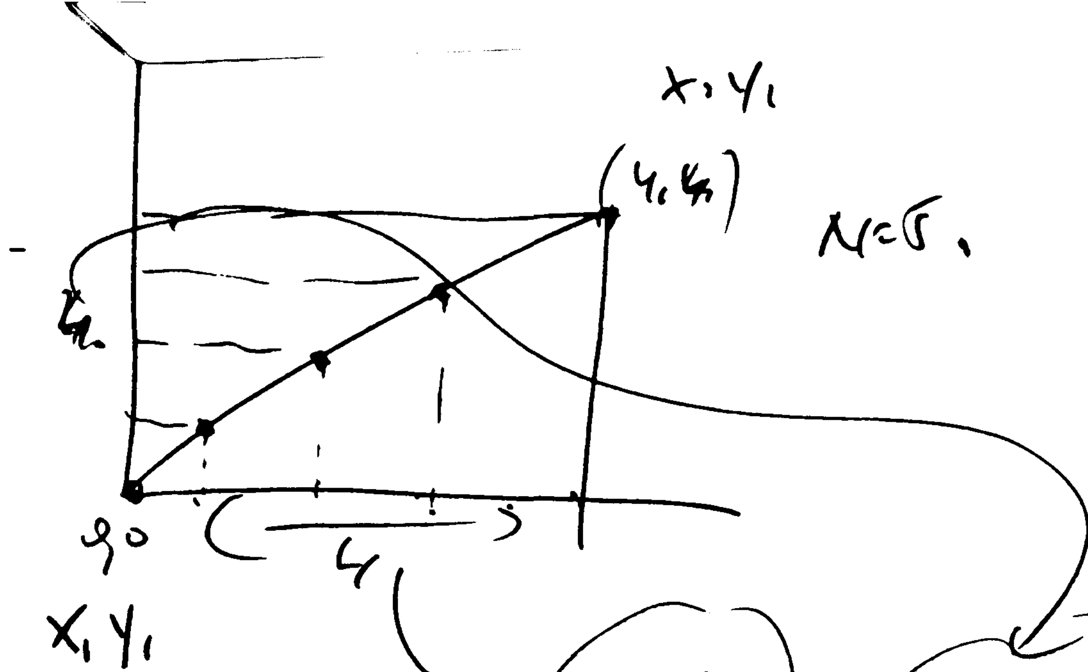
(Length)



N = [illegible].

SA? N=5.

$$\frac{\text{Length}}{N-1} = x$$



N=5.

$$\frac{x_2-x_1}{N-1} \qquad \frac{y_2-y_1}{N-1}$$

x1 y1 x2 y2 N=5. FIRST FORMULA

x step
y step

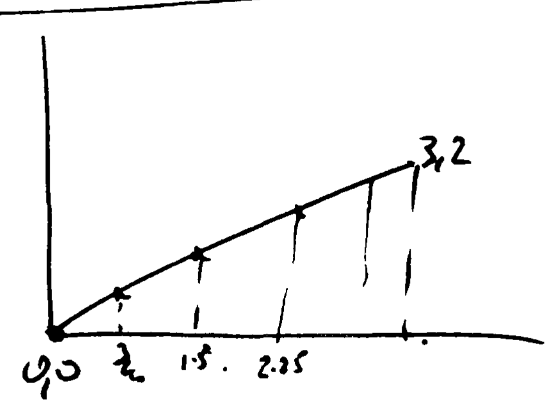
$$x\,step = \frac{x_2-x_1}{N-1} \quad \left(\frac{4-0}{4}\right) = 1$$

$$y\,step = \frac{y_2-y_1}{N-1} \quad \left(\frac{4-0}{4}\right) = 1.$$

First point

First point	2nd	3rd	4th	5th
x_1, y_1	$x_1+\left(\frac{x_2-x_1}{N-1}\right)$ $y_1+\left(\frac{y_2-y_1}{N-1}\right)$			$x_2 y_2$

→ Accumulate function.



N=5.

$$x\ \frac{3-0}{4} = \frac{3}{4}$$

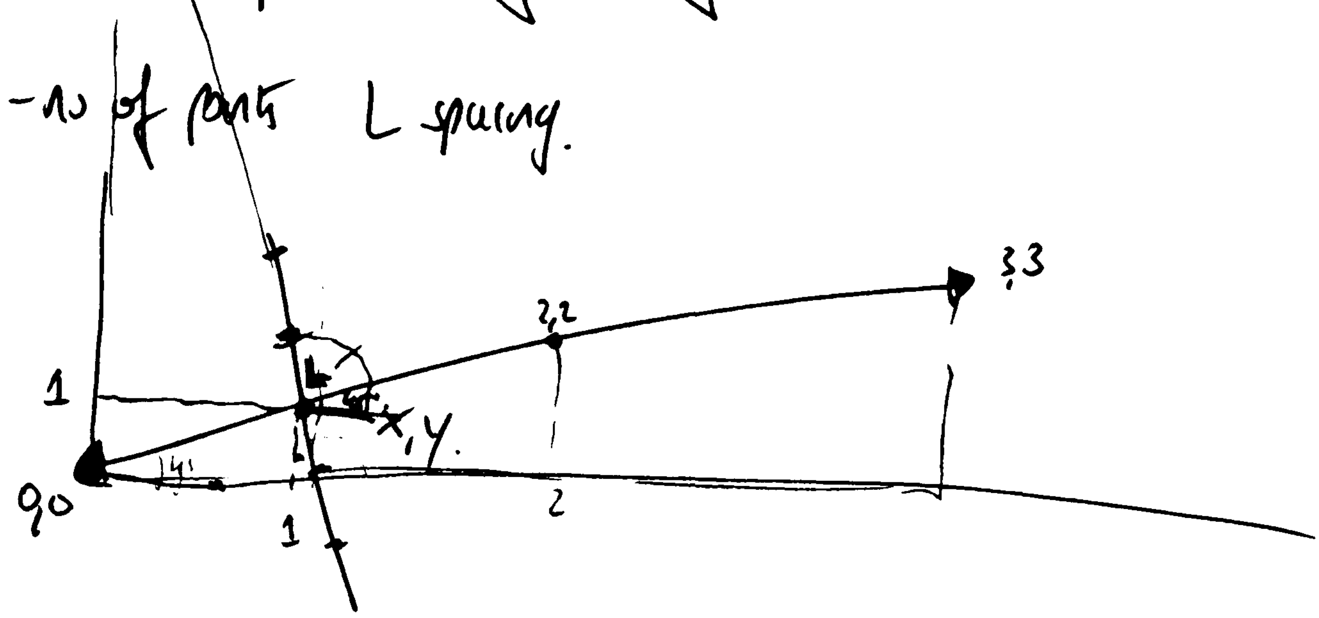
$$y\ \frac{2-0}{4} = \frac{1}{2}.$$

5

(B) 2ND PROBLEM :

N co-ord pairs along line segment.

M - no of points L spacing.

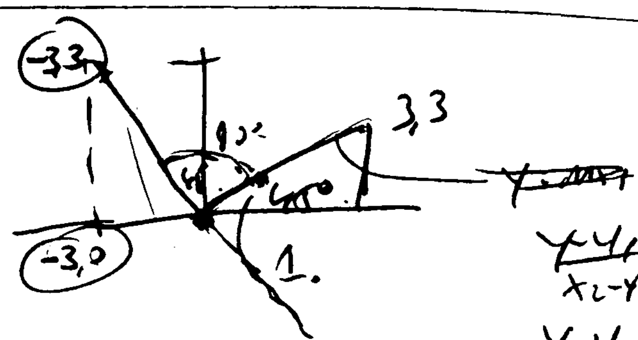


Slope = $\frac{y_2 - y_1}{x_2 - x_1} = \frac{1-0}{1-0} = 1$. $\tan^{-1}$ 45°.

(1,1) $y - y_1 = m(x - x_1)$. ~~$y = mx + c$~~

0,1

0,0



$\frac{y_2 - y_1}{x_2 - x_1} = m$

$y_2 - y_1 = m(x_2 - x_1)$

$y = -x$.

~~$x = 1$ $y = -1$~~

$x = -1$

$y = -x$.

$x = -1$

$y = 0$

~~$3 - 0 = m(3 - 0)$~~

$y - y_1 = m(x - x_1)$

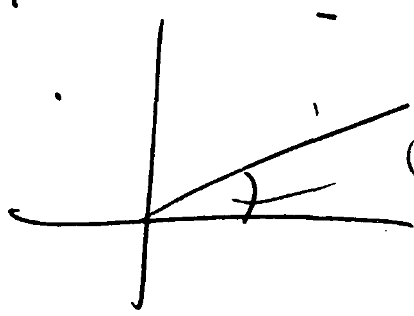
$y - 3 = 1(x - 3)$

$y - 3 = x - 3$

$y = x$

$y = -x$.

$y = -x$.



(-).

$y - y_1 = (m(x - x_1)$

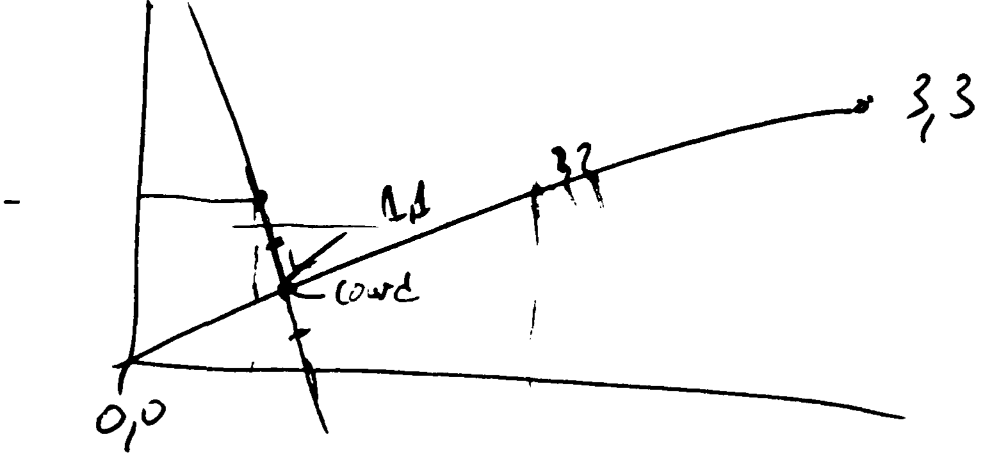
$y = x$.

$y = -x$.

~~$y = -x + 3$~~

$x = -1$ $x = 1$

$y = 1$ $y = -1$



SLOPE $x_1 y_1$, $x_2 y_2$ } 0.   Slope = $\left(\frac{y_2 - y_1}{x_2 - x_1}\right)$ [illegible] = M.

Know – 1 point on each line.

$y - y_1 = M(x - x_1)$ $M = -m$.   ($y = -x$.)

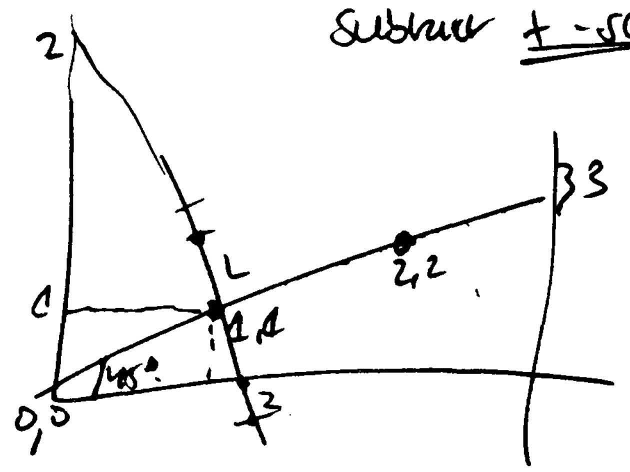
eq'n for line.

Negate the x co-ord

1,1 → (x slp 3/4   1·75
y slp 1/2)

Subtract x slp.

Subtract x-slp



$y - y_1 = M(x - x_1)$

$y - 1 = -1(x - 1)$

$y - 1 = -x + 1$

($y = -x + 2$.)

$x = 0$
$y = 2$

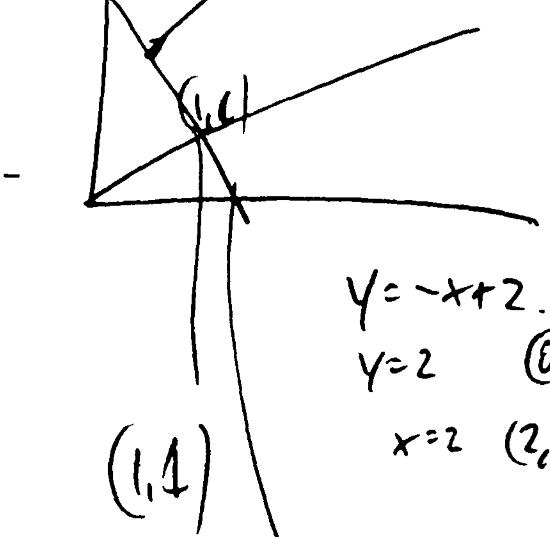
(0,2)   (1,1)

$\frac{3-0}{3} = 1$ 1,1

$\frac{3-0}{3} = 1$.

(1,1)   (2,0)   (0,2)

add x slp subtract y slp



y = -x+2.

y = 2 (0,2)

x = 2 (2,0)

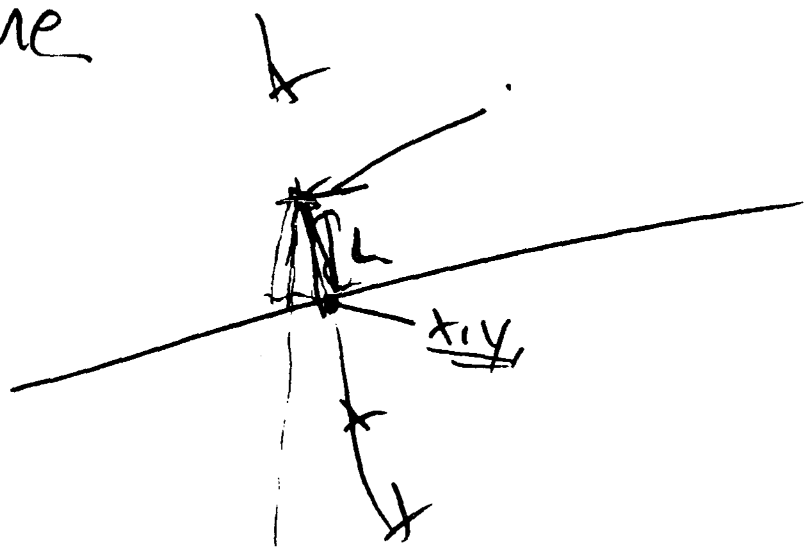
add xstep subtract ystep

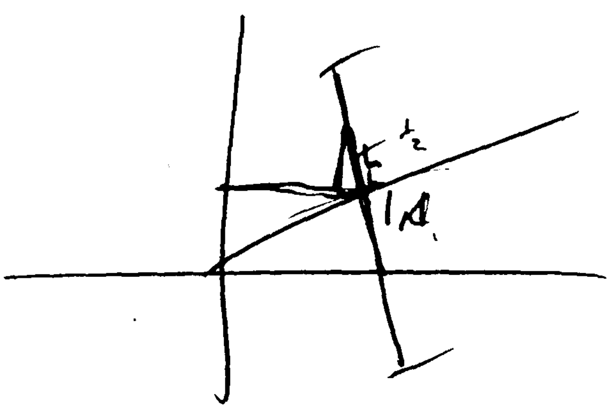
(1,1) (+xstep, -y-step)

Point on Line

x_1, y_1

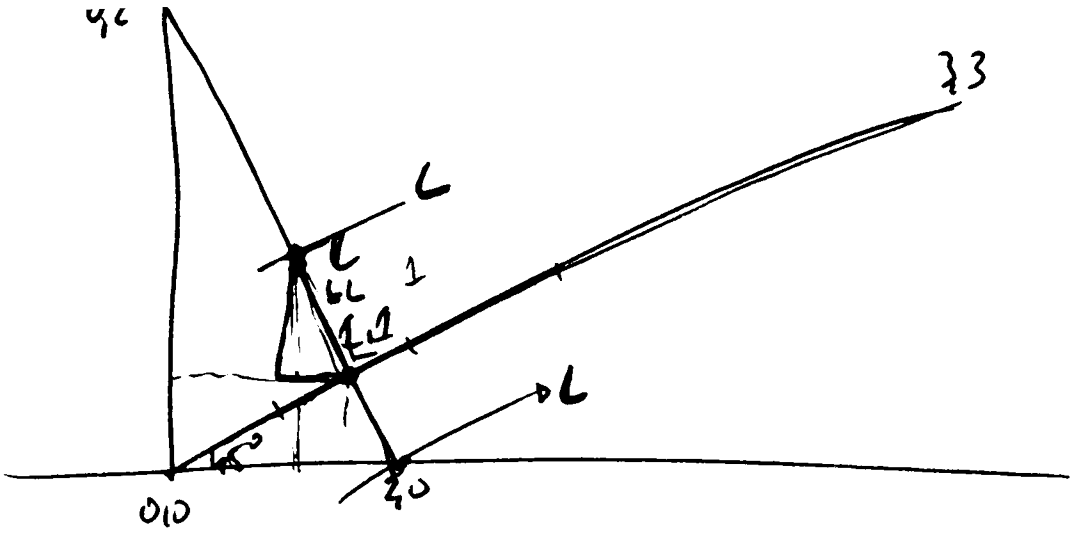
L = slope factor.





L = 1/2

y = -x+2.



$y = -x + 2$

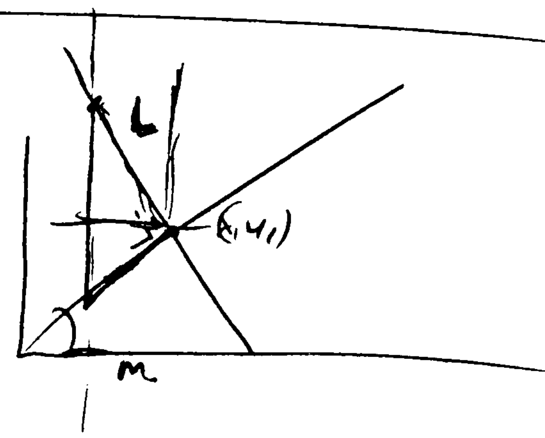
$L = \frac{1}{2}$. (1,1) $\frac{1}{2}$, 1.5.

(4) parts segments:

M parts L ⊥.

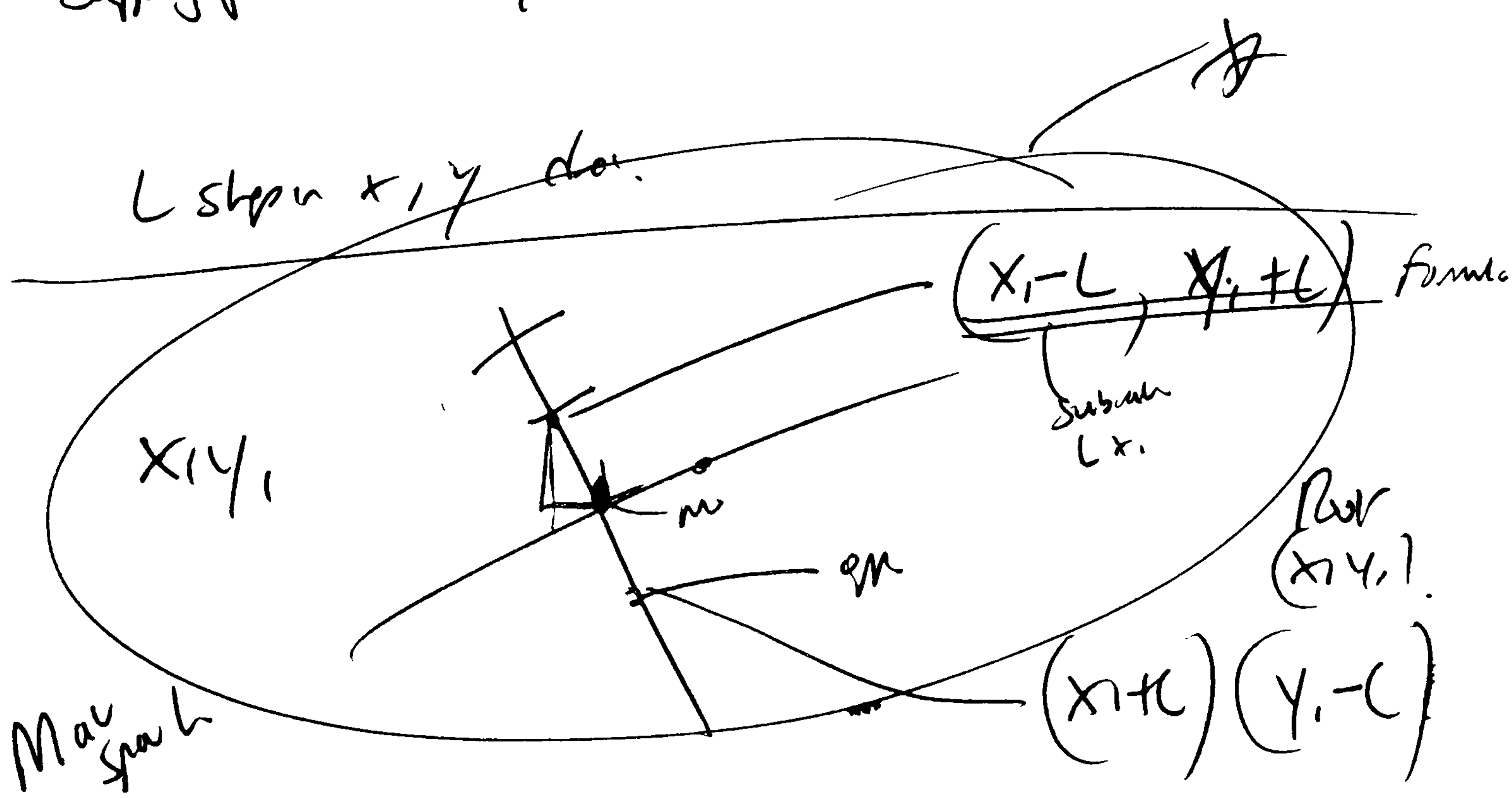
Slope of 1st line + point on line

New slope = − first slope

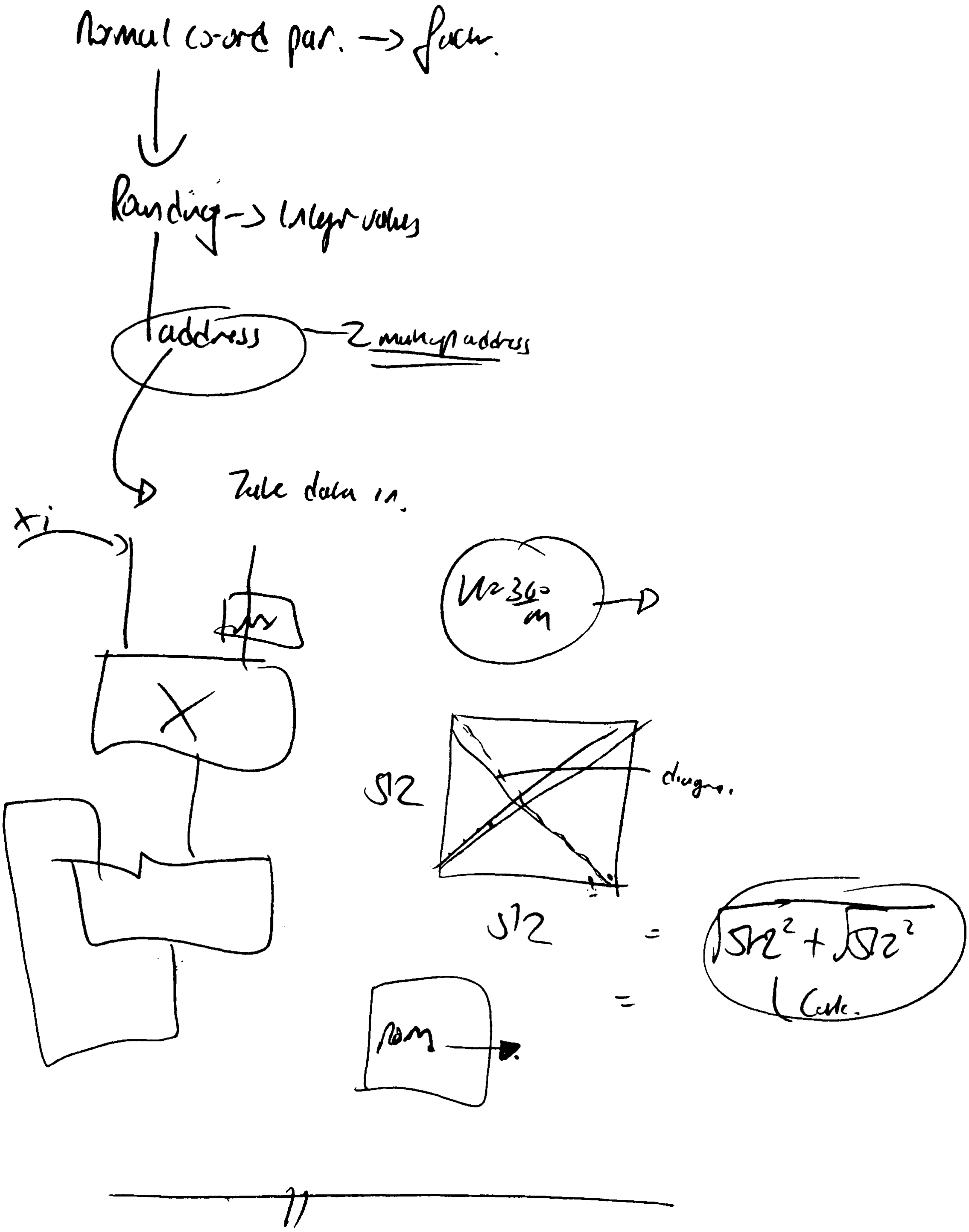


Stepping factor in x and y direction = L

L step in x, y dir.

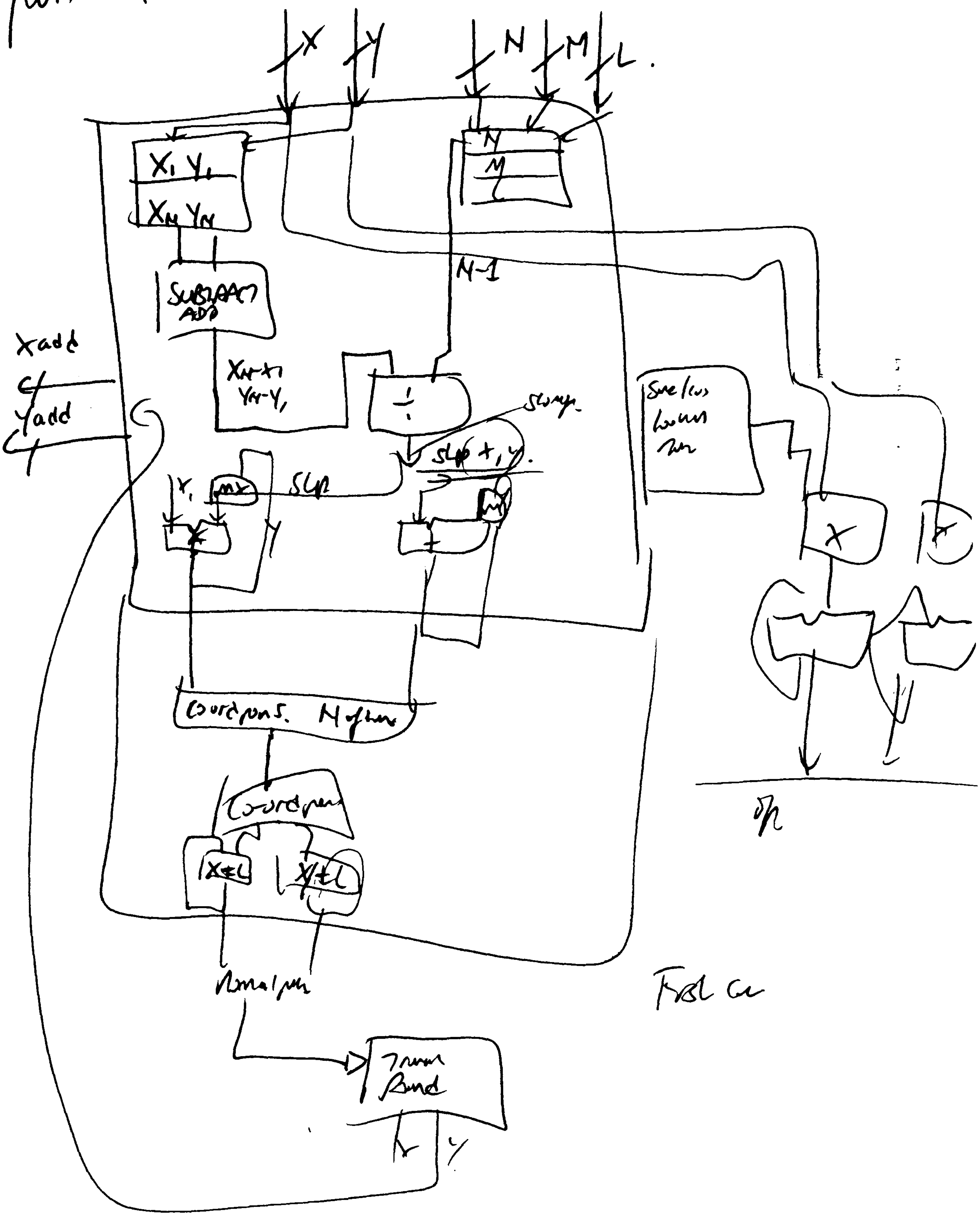


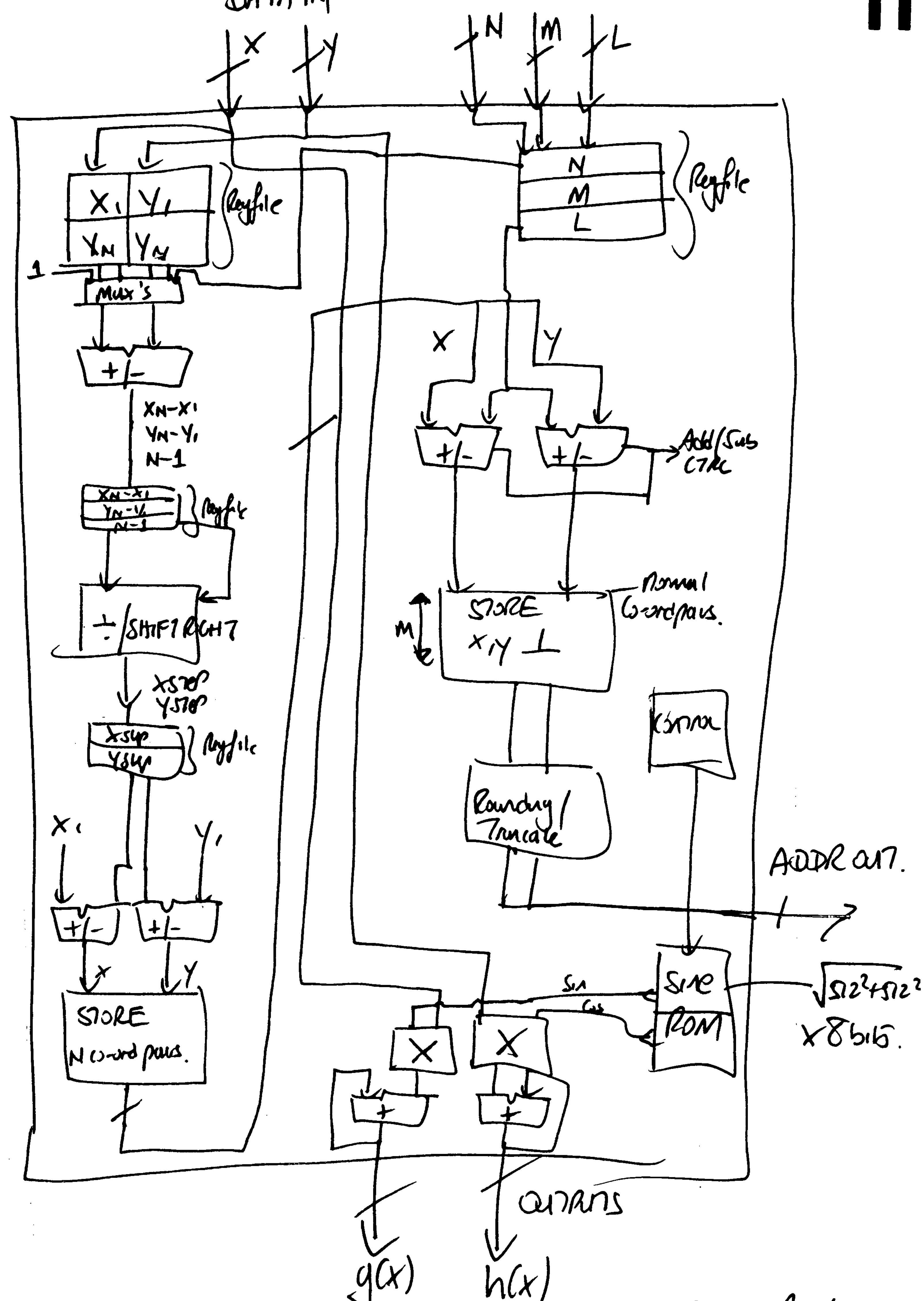
(C)


Normal co-ord par. -> fact.
Rounding -> integer values
address
2 multiply address
Take data in.
xi
√2
diagonal
√2 = √(√2² + √2²)
calc.

H/WARE.

Data IN.





* For full precision -> 4 data pipelines. So that write in Raw Pixel + rely mean at same time

B.2.2. DS'S VERBAL PROTOCOL AND DESIGN WORKINGS

00.00.00
(READING PROBLEM SPECIFICATION, UNDERSTANDING INPUTS, UNDERSTANDING FUNCTIONAL REQUIREMENTS, MAKING NOTES) You are required to design an integrated circuit to perform the following computer vision task. Process an area of RAM memory that contains a 2-D TV image .. a 2-D TV image .. The chip will be sent two X, Y coordinate pairs .. X, Y .. X, Y .. and constants N .. M .. and 1 .. - looks like a gamma .. OK .. The coordinate pair .. that start .. and that lot end .. define the position of a line vector drawn over memory. The chip then has to calculate ... N coordinate pairs along the line vector ... Right ... I have to check that a moment .. At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given line vector. Using stepping factor 1 form M coordinate pairs .. Right .. OK .. At each normal coordinate pair fetch the nearest pixel from memory ... and summate its value according to the expression below .. generating two data items for each normal vector, g(x) and h(x). Right. OK. So we're given those .. Now I'm assuming that we're actually organising the memory on a row and column basis .. because that makes a hell of a lot of difference. It means I don't have to work it out on each cycle. It just means I have to have an extra stage in there somewhere .. Right we want to calculate g(x) ..uh .. h(x) .. uh ... and x and y along that line and then along that line there .. So .. two lots of those .. OK .. Now N coordinate pairs along the line vector .. Right. N is 8 in that case .. So we've got start and the end, and we've got 1, 2, 3, 4, 5, 6, 7 .. 8 .. So it's 8 .. So ... Let's see .... So N coordinate pairs .. N coord pairs includes end points - for a start .. and I assume that that one - M - .. M is 5: 1, 2, 3, 4, 5 - is the same ..

00.02.50
(SELECTING SUBPROBLEM, QUESTIONING SELF) Right. OK. How do we calculate the N coordinate pairs along the line vector?

00.02.56
(STATING INTENTION) Well let's work that out. Let's work that out .. Uhm .. N coord pairs along vector. Right ....

00.03.11
(STATING INTENTION) Actually let's be sensible ... uh, and do like a top level thing of this thing.

00.03.16
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, MAKING NOTES) Right we need to do that .. What else do we need to do? .. For each, uh, N .. do .. M .. coord .. pairs along .. normal .. vector .... Right .... Do (a). And (b) .. calculate .. two data items for each normal vector .. OK .. g(x) .. and .. h(x) .. Right. So, we generate those lot and for each one of those we go along that and generate those results.

00.04.18
(EVALUATING PROGRESS) That's a lot better. So that's all we need to do.

00.04.21
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) Now .. Sine and cos ... and Multiplies and Sums .. Right ..

00.04.30
(RE-SELECTING SUBPROBLEM, QUESTIONING SELF, MAKING NOTES) How are we going to do the lines along there? .. So it's: Generating .... the coordinate pairs .... from starting values ....

00.04.56
(TIME-FILLING VERBALISATION, READING HELP SHEETS) Right. No doubt there are lots of clever ways that you could do it ... I might know of a few .. Well not really .. I'm not very good at that.

00.05.08
(SPECIFYING DESIGN CONSTRAINT, READING HELP SHEETS) And we actually want to know the xs and ys quite accurately. I suppose to the nearest pixel .. Actually there's no .. Well x and y are integers I suppose ...

00.05.24
(GENERATING MATHEMATICAL SOLUTION CONCEPT, READING HELP SHEETS, SKETCHING GRAPHICAL MODEL) Right .. Well we've got sines and cosines anyway, so we can probably do this .. We are going to have to have sines and cosines in there somewhere so we might as well use them to generate the lines in the first place .. Right .. So .... OK .. x1 .. Oh, the wrong way 'round! .. x1 .. Actually x-start, x-end ... y-start, y-end ..

00.06.09
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, MAKING NOTES) Uhm .... Worry ... about .. the direction .. of the line .. later .. Use .. uh .. positive and negative values for N. OK .... Ah Right.

00.06.36
(EXPLAINING TO INVESTIGATOR) .... <Experimenter Prompt> .. Yes I'm just trying to think of something.

00.06.41
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) Right. Let's use the good old fashioned method I suppose. We need to develop .. uhm .. as we step along it ..

00.06.50
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, APPLYING KNOWLEDGE OF HARDWARE CONSTRAINTS TO MATHEMATICAL SOLUTION CONCEPT) Right .. A division, hey! .. That's a pain in the bum that is! .. Right. Oh, hang on!

00.06.55
(QUESTIONING SELF) Does it say N coordinate pairs?

00.06.58
(TIME-FILLING VERBALISATION) Yes ... Well if we .... Oh dear! .... <Experimenter Prompt> ..

00.06.11
(EXPLAINING TO INVESTIGATOR) Yes, I'm just trying to think of which way 'round to do it, you see.

00.07.14
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) Now we could either ... Yes the best way to do it is to actually step along its length itself and generate the x and y at those points themselves .... Yes there's a lot of involved maths here that I could probably avoid .. with a bit of thinking ..

00.07.34
(STATING PLAN) Right. Well we'll do it in stages and perhaps we can see what happens later on.

00.07.40
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSION) Right. We've got y = mx + c .. Good old equation for a straight line .. Yes .. and that's a y position equals. Now .. and m equals .... Actually you can probably do it from similar triangles actually .. I'm going to do it from similar triangles ..

00.08.06
(STATING INTENTION) Right .. Let's have a look at that ...

00.08.13
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) Yes .. Righty ho! .. Ah! That's why I didn't want to do it that way ..

00.08.19
(GENERATING MATHEMATICAL SOLUTION CONCEPT) Well you can either pick to go along x or pick to go along y.

00.08.24
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, MAKING NOTES) Now that might be embarrassing if it's a vertical line or a horizontal line. So you have to check for .. check for .. horizontal .. or vertical lines ...

00.08.40
(GENERATING MATHEMATICAL SOLUTION CONCEPT, EVALUATING MATHEMATICAL SOLUTION CONCEPT, APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS, MAKING NOTES) Can't really use the hypotenuse .... hypotenuse .... Or could do actually. Could use a square root table .. Ah square roots expensive! .... But I could use a table. Yes .. Could .. however use a table in ROM. Well I'm going to have to do that anyway .. for .. square roots .. and sines .. 'cos we can calculate cosines from sines anyway. Quite easy ... Righty ho! If I do that it makes a hell of a lot of difference doesn't it, 'cos then I can calculate what those two are .. Right ... Let's think .. Righty ho! .... Tell you one thing. If I could work out the, uh .. Yeah. Let's do it that way .. Right .. If .. I use stepping .. along .. hypotenuse .. Although - Oh, hang on! .. Ah .... Let's check for a minute .. Yeah .. Let's see. 512 by 512 .. Yeah .. Sum of the squares. Oh dear! Could be a bit expensive in memory. 512 by 512 .. Yes that's too much .. No can't do that .. Too much memory required .. Too

much .. mem' required. I'll not do sines and cosines.

00.10.41
(STATING INTENTION) Right .... Let's have a little look at this ....

00.10.48
(TIME-FILLING VERBALISATION, SKETCHING GRAPHICAL MODEL) Well let's assume I've done that .. OK .... Right .... OK ...

00.11.02
(RE-STATING INTENTION) OK. Let's see ....

00.11.09
(EXPLAINING TO INVESTIGATOR) <Experimenter Prompt> OK. I'm not verbalising at the moment, I'm just drawing the damn thing down .. 'cos I'm a little bit stuck again to work out the positions of the things.

00.11.22
(RE-STATING INTENTION) OK. Let's have a little look at this .. Let's see what we want to do ..

00.11.26
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, APPLYING KNOWLEDGE OF HARDWARE CONSTRAINTS TO MATHEMATICAL SOLUTION CONCEPT, MAKING NOTES) Oh gosh! All square roots and things here. I don't want to do that ... Square roots are a real pain .. they really are .. A real and utter pain .. Dividing is a difficult thing to do as well, but we can get around that by multiplying .. OK .. Multiplying ... and shift .. for divide. Straight forward. It's rational logic isn't it .... eg 8 divided by 255 - to remind me how to do it ..

00.12.10
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS, EVALUATING MATHEMATICAL SOLUTION CONCEPTS, MAKING NOTES) Right .... OK .... Calculate ... delta x and delta y. That's easy enough. That's x-2 minus, uh, x-end minus x-start and ... y-end minus y-start .. Then we can divide them up .. So finds .. this .. Finds the increment .... This finds the stepping value I suppose .... value. Now you've got to be careful for errors here .. 'cos of the size - if it's a vertical line .. Yeah .. vertical and horizontal lines again .... 'cos I don't really want to calculate that .. Righty ho! .. So we've got that. OK. Simplify - 'cos you just divide it by .. Now let's look back to that .. By dividing by the delta x, delta y by now .. Let's see, the stepping value is 1, 2, 3, 4, 5, 6, 7. OK. That's 8 .. So 8 units along .. Yeah .. And the stepping value is 1 .. So it's divided by the total isn't it. So length divided by 1, 2, 3, 4, 5, 6, 7 .. Ah no it's not! That's a total of 8 .. Yeah. There are 8 increments .. Hang on - stop a moment .. N coordinate pairs along the line vector .. Right. That means you got to get that one, that one, that one, that one, that one, that one, that one .. To generate them .. you have to divide that total length by how many, into how many areas: 1, 2, 3, 4, 5, 6, 7 .. OK. By (N - 1) .. Right .. Then you've got like a little 'for' loop .. - in algorithmic terms .. terms .. - to calculate first set of pairs .. Ah .... That's easy .. You just go ... 'for' number of times .... 'from' ... . Well let's see.

We've got x, we've got two variables: x and y, and that's equal to x-start, y-start .... OK .. For number of times from 1 .. OK. We start off from 0 - 1, 2, 3, 4, 5, 6, 7 .. to (N - 1) .. So we decrement that. That's no problem .. Then we just go ... That's a bit of trouble actually .. Oh no, that's OK! .. Pair x .. Pair y .. equals .. OK. X, Y. Then we've got x equals x plus .. x increment, and y equals y plus y increment .... OK .. right .. Now these .. are used .. as, uhm .. So that's the thing that outputs the pairs .. Right. These are results .. That will be used to generate normal pairs .. Uhm ..... Well that's how you do that .. Remember to check for vertical and horizontal lines .... That's easy .. see if x-start and x-end are the same, and then you'd just have to stop that doing it .. and then you'd go next line .. and next number .. Now the good thing about that is that I can use that .. uh .. as the actual (unintelligible word) at the normal as well ..

00.18.51
(STATING INTENTION) Right. I'd better write that down.

00.18.55
(MAKING NOTES) This can be used to generate the normal pairs .... This algorithm .. That's OK isn't it! .. We'll have a bit of test logic in there ....

00.19.21
(SELECTING SUBPROBLEM) We want to connect, find the end ones now .. Uhm ... Right .... We've got .. Now the only problem you've got to do is to generate .. You've got to work out x .. We know x-start ..

00.19.44
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, MAKING NOTES) We know we can do .. a normal set in two parts .. OK .. (a) is that one, and (b) is that one ...

00.20.12
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, READING PROBLEM SPECIFICATION, MAKING NOTES) Now is that going to work .. N coordinate pairs - using stepping factor 1 .. All right. Well that's not going to work possibly is it .. because uhm .. we don't know how .. We can't do this .. We can't do this because .. may be even number.. 1, 2, 3, 4, 5 .. even number of pairs .. even number of points .. So have to do it slightly longer .. Slightly longer. Right.

00.21.03
(SKETCHING GRAPHICAL MODEL, ATTEMPTING TO RECALL) Now generating a line at a tangent to another line .. Creating end points .... Ah gosh! I wish I could remember the trig'. I really do.

00.21.30
(STATING INTENTION) Let's look at this thing. Let's see if it says anything here

00.21.33
(READING HELP SHEETS) I want some of the theorems really. Some of the trig' theorems ..

00.21.38
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) Right. That's my angle ... alpha ... And we've got an alpha there as well .... So we can calculate alpha because alpha is the same as k .. And we've got a point there which is x and y .. That's alpha minus 90 ... And that's .... x-start, y-start .. and that's x-end y-end ...

00.22.33
(RE-SELECTING SUBPROBLEM, ATTEMPTING TO RECALL) How are we going to do that? .... <Experimenter Prompt>

00.22.50
(EXPLAINING TO INVESTIGATOR, EVALUATING MATHEMATICAL SOLUTION CONCEPT) I just keep having different ideas all the time .. Uhm .. Because this one looks .. This particular method works better by actually working out M .. Uhm .... Yes ..

00.23.10
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS, MAKING NOTES) That looks interesting doesn't it! .. That's alpha minus 90 there and that's alpha up there .. Well that's interesting .. OK. So that's 90 there. So .. that goes across .. Ah! That looks interesting .. So that thing there is .. Uhm. Well if that's alpha minus 90 and that's alpha, that angle there must be 90 .. If that's 90 and that's alpha then that must be alpha minus 90 there ..

00.23.40
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) All right this looks good! .. This is looking good .. Right ...

00.23.48
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, EVALUATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS, MAKING NOTES) Now .. Well we know .. uhm .. stepping factor, N and M coordinate pairs .. No .. wrong one .. Ah, that's right. We know that .. and we know that ... Now N coordinate pairs - 1, 2, 3, 4, 5, 6, 7, 8 there .. 7 things .. So .. So length .... Uh .... Ah. Right .. So length of that there .. Ah, dear me it's backwards on - it's a real pain!.... Ah that's better! .. Alpha minus 90 down there .... OK. Ah this is easy enough! So length equals that times (N - 1) .. Uhm .... Right. OK .. Uhm ... Now to do that .. I'm going to have to use sines and cosines. This is ridiculous .. I've got to use sines and cosines at some stage. I might as well for this .. So 1 and M . So length is that .. Now that's half of it there .. Right that's half of it over there .. OK .. right .. So demi-length ... is that ... over two which is easier to get .. Right .. We've got that now .. now ... Uhm. This is interesting .. Ah dear! .. We've got sines and cosines .. Now .. delta .. Sorry .. Yes. Delta y equals .. delta y is, uh .. Now let's have a look at that one here .. Delta Y .. delta Y. That one there, is adjacent and that's hypotenuse. That's cosine .. cosine. Hang on! Uhm .. Let's see, cosine of a equals .. Let's see ... cosine is adjacent over hypotenuse. So it's equal to delta y over delta H .. Yeah. And sine will be equal to .. sine is equal to the opposite - delta x

over delta H .. Now you've got delta h in there .. So delta y equals cosine alpha times delta H .. And delta x equals .. Oh this seems silly! .. Uhm ... sine alpha times delta H .. Oh this is not too bad! .. Then we can plug them into those ... Then we can plug .. use ... Let's see, x-start .. Ah, equals .. Let's see .. x-start is down there, is equal to x .. plus delta x .. x-end equals .. x minus delta x .. y-start .. y-end. Ah, this is easy in this respect! ... Oh! .. x-start .. There's x-start, y-start's down there. So that's y minus delta y, and y plus delta y down there .. Then plug that .. that .. into .. uhm .. iterative algorithm .. Ah! .... (1). Right .. So gives you that and you just whack that into that equation there .... This generates .... pairs .. to .. Accumulate .. to determine g(x) and h(x) .... Right ....

00.29.24
(SELECTING SUBPROBLEM) .... Oh well .. Let's see, now .... Uh huh. g(x) and h(x)

00.29.50
(EXPLAINING TO INVESTIGATOR, EVALUATING PROGRESS) ....
<Experimenter Prompt> Yeah. I'm just thinking a minute. Ah. OK. This is great ..

00.29.55
(UNDERSTANDING INPUTS) So we've got .. Now for g(x) we've got inputs .. We've got .. uh, M, nought .. Uh .... Right. Well that's easy enough .. Actually we can .. This is easy to do actually in hardware terms actually - to draw it in ..

00.30.24
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) For g(x) .. we have .. Right. We have .. k times i for a start .... Times k .. i .. Yep! .. And then that is used to generate a sine .. OK .. we've got sine. OK .. And then that is accumulated .... with an old value .... with .. That's plus and then we've got .. OK .... Oh bugger! It's not (unintelligible word) .. multiply it with another one .... xi is a pixel .. Yeah!.... Hang on a minute! .... Ah let's see .. xi equals a pixel doesn't it - it must be .. xi is current pixel. Yeah! .... So .... How do we generate?..

00.31.55
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) That's not too bad is it?! ...

00.31.57
(QUESTIONING SELF, GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT) Now do we do this as an algorithmic type thing?

00.32.02
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPT) Yeah, it's probably better ..

00.32.03
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT, QUESTIONING SELF) Or do we do it as a flow-through thing? ..

00.32.06
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) I don't know ...

00.32.09
(SELECTING SUBPROBLEM) For h(x) ..

00.32.12
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) It's exactly the same isn't it really .. Uhm .... M times .... It's the same ... It's just a cos block there .... Right. So .... OK .. i. cos block there ... Times x(i) .... Plus - yeah. It's a summation - of the old value .. OK. Right ....

00.33.03
(SELECTING SUBPROBLEM, QUESTIONING SELF) So .. now .. we've come to the implementation ... How are we going to implement it? ..

00.33.09
(SPECIFYING PERFORMANCE CONSTRAINT) Well all right .. it's a vision task .. So you've got to do it quite fast ..

00.33.15
(QUESTIONING SELF) So .. how to do? ...

00.33.23
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE CONSTRAINTS TO ABSTRACT HARDWARE SOLUTION CONCEPTS, MAKING NOTES) Well we need to do sines and cosines .. Now they're quite slow - doing it algorithmic .. Uhm, how many do we have to do? ... Well we have to .. each time we do it we have to do a sine and a cosine (unintelligible word) So it's probably best to use a look up table .. So say we've got a look up table ... table .. But sines and cosines are similar ... So .. can be derived .... uh .. from one another .. So only one table and you only need nought .. uhm, to forty-five degrees I think it is .. Yeah, well ... Or is it nought to 90 degrees, or something like that - I think it's not forty-five degrees because it's reflexive, all right, in that origin .. So that's quite small .. We need a little bit of a division - Do we need a little bit of a division? ... Yeah need a little bit of division .... But that's easy enough because you just multiply .. and then divide ... Yeah ... Uhm .... OK ... Do we need division - Oh yes, we need division ... Unless we can use sines and cosines to generate .. uhm ... that .. Oh no, we still need division .. to actually .. uh .. do that .. Multiply is OK .. Plus is OK .. Uh .... dividing ... by ... a number .. is a pain .. Dividing is a pain .. So .. I have to .. And a possible answer ... is to .. multiply by 1 over number .. Yeah .. so we need a table .. So recip' table we need, and shifts .. It's going to be a bit of a (unintelligible word) to do that type of thing .. Well it depends what the number of N are .. 'cos you might not need that much memory to do it - maybe .. you could do a division table perhaps .. I mean you're not dividing a thousand by a thousand - it can't be a million bits ... Righty ho! .... So .. Uhm .. This is the inner loop ... and we need that type of thing there ... Uh .. So is it .. going .. to be flow-through ... - yeah, from left to right, say -.. or .. an engine type thing? .. I think it's going to have to be an engine .. really ..

though that type of thing - g(x) and h(x) could be done quite well .. So .... g(x) .. and h(x) are most critical .. parts .. Yeah .. So put most of effort there .. there. Right .. Now, is that actually a sensible way of implementing that? Well I can see some form of commonality there already .. Yep .. We've got x and y .. Righty ho! .. Now .. So ..

00.38.02
(STATING INTENTION) Let's create the h(x) and g(x) blocks ...

00.38.08
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) Right .. We are going to need .. multiplying .... going in there ... very similar to the other drawings .. OK ... Right .. Uh, that gives a value for alpha .. That's a multiply .. That's k .. That's i .. Uh huh. Uhm ... The sine alpha comes back from outside ... Goes into another multiply .... Yep .... Uh ... OK. Cosine k.i .. Right .. Now we can use two tables, or .. not really that worrying actually .... cos .. alpha there .. And then we want the pixel - is that the pixel? .... k and i - yeah that's right .. OK .... So ... xi - Ah this is much better! ... Uh huh .. So that there is xi sine k.i .. and that is xi cos k.i .... Right .... Ah the rest of it's not too bad now! - There's the difficult bits .. to do .. A bit of spare paper hanging around - Get rid of that - Don't need it ... Righty ho! .. Now all we've got to do is generate k, i and xi ... So. Well .. Uh. The other bit can more or less be almost a bus, can't it ... uhm .. like a state machine .... almost ... Need .. some form of generator for x and i .. Well let's call it that shall we ....

00.41.01
(EVALUATING PROGRESS) Oh dear! I've done things slightly in the wrong order .... I really should have done an overall view ..

00.41.09
(STATING INTENTION) Let's do an overall view here, just to .... overall ... view ....

00.41.19
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Right .. OK .. We go .. We've got x .... x .. x-start, end ... y-start, y-end .. OK .. Uh .... OK. N, M and thingy .. N, M and l ... probably (unintelligible word) into registers or something internally ... It doesn't say anything .. otherwise it's going to have loads of pins on the damn thing .. Right. OK. We've got .. We've got the g(x) ... g(x) .. h(x) .. block .. with .. k, i ... xi, going in .. Uh, a going out of alpha .. Value coming in .. Well at the moment we'll just do it of sine, and cos - because you can do it outside - it's no hassle - coming in ... and out of that come xi.sine(k.i) and xi.cosine(k.i) .. And then we have the block that generates .... generates .. Right .... uh, x ... y .... k .. i .. Oh, and all the other logic as well - You've got like, uhm .. control logic here ....

00.43.41
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) But that's not too bad

now.

00.43.43
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) This is the control .... and sequencing .... All these lot go into there .... and it's going to ...

00.43.57
(SELECTING SUBPROBLEM, QUESTIONING SELF) What's control and sequencing going to have in it? ..

00.44.01
(COMMENTING TO INVESTIGATOR) Oh, I'll do a little bit more Linden, all right. Just a little bit more and that will be it ..

00.44.07
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) I'm not too satisfied with that way of doing things - but at least I can .. do it ..

00.44.14
(GENERATING HARDWARE SOLUTION CONCEPTS, INTEGRATING HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Right. So control and sequencing .. I'm just going to have it, like, so it does the two loops .. just does two loops .... So .... you've got the control bit .. Control and sequencing ....

00.44.33
(SELECTING SUBPROBLEM, SPECIFYING DESIGN PROCESS CONSTRAINT) I'll just do the sequencing because that's easy .. the easiest bit ....

00.44.39
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) OK .. We have all this .. All right .. Stack for .. uh .... x ... Y pairs ... Well for the nesting .. nesting, 'cos you've got two levels .. and then you've got .. an adder .. for x and for y .. So it's like .. two adders .. Uhm .. Right .. Then you've got .... Uh .. Oh bugger! .. You've got the increment .. increment .. register .. Right. And you've got .. the result .. Well this is duplicated anyway .. Register .. So .. They're coming in there .... You've got some way of clearing this - so you've got this clear clock .. type of thing .. So you've got x (y) because there's another one .. Duplicate .. duplicate .. for y .... Stack for x nesting .. Well I hardly need to do that actually, really - It's hardly worth it .. to do for the two things ... So .. Uh. Multiply by the four .. for .. outer loop .... and inner loop .... Right .... Uh huh. Now .... we can also ....

00.47.03
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) All right .. Oh that's not too bad because you can - you've got the control logic out of there ..

00.47.11
(SELECTING SUBPROBLEM) Uh, control ..

00.47.14
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, MAKING NOTES) You've got various things for the increment - I think it's the increment isn't it? .. OK .... increment and various controls .. control .. input .. Uh .... No, no, no .... Uh huh. Oh you can write it in different ways couldn't you really .. You could write it into the .. You could put it into the increment .. Put it in .. into the result, and then put a new value in. So you can cope with that .. So you put the control .. The control's got to .. uhm .. derive .. Yeah .. Get delta x and delta y .. Put them in .... Oh .. Divide by N - 1 .. N - 1 .. Well that's just a bit of logic .. for ah .. So it's .. decrement .. and multiply by 1 over .... by 1 over (N -1) .. And .. Let's get a (unintelligible word) out there ..

00.48.46
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) Oh that's not too bad! ..

00.48.48
(EXPLAINING TO INVESTIGATOR) I'm going to stop it there roughly - 'cos there's no need to carry on really, is there? It's supposed to be conceptual, all right .. I could carry on for ages more but I don't think there's any need ..

00.49.02

x / } X ↑ Start ✓
X ↑ end. ✓
N ✓
M ✓
l ✓
g(x) ?
h(x) ?
(X,Y) 2. ?

N coord pairs includes endpoint
Same for M.

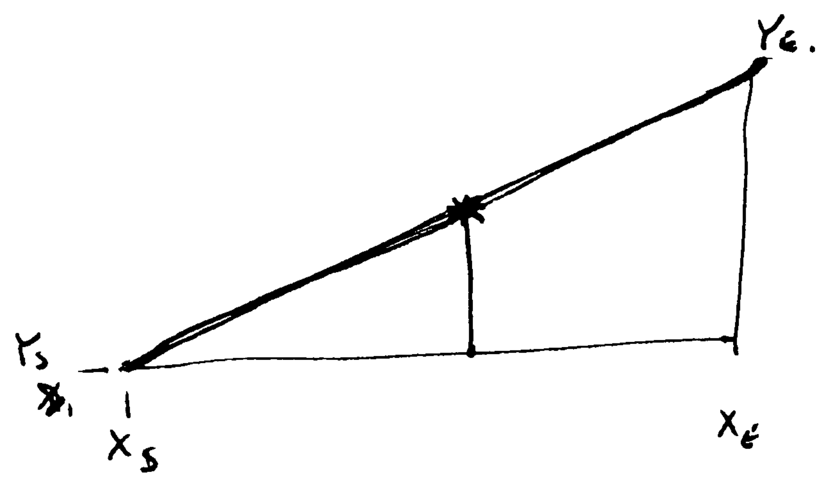
---

① N coord pairs along vector

② . For Each N do a) M coord pairs along normal vector.
b) calculate g(x) & h(x).

---

generating coord pairs from Starting values.



worry about direction of the line later.
use ±

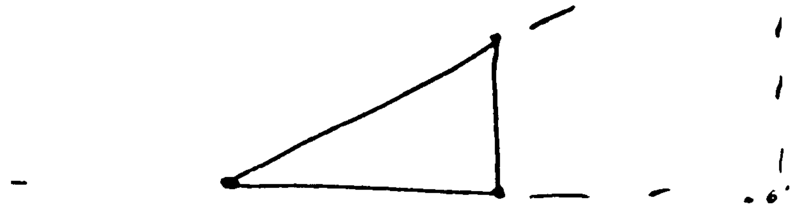
check for horizontal or vertical line

~~y = mx + c~~ ?
mx

If I use stepping along hypotenuse.
No (too much num accuracy)

can't use hypotenuse, as square root expensive.
could however use a table in Rom..
For Sqrt's and Sin's

~~512 x 512~~



Shift for divide rational

eg. $\frac{8}{255}$

calculate $\Delta x = X_E - X_S$

$\Delta y = Y_E - Y_S$

This Finds Stepping value. (carefully for errors. line vertical & horizontal lines)

by diving either Δx by $(N-1)$

Δy $(N-1)$.

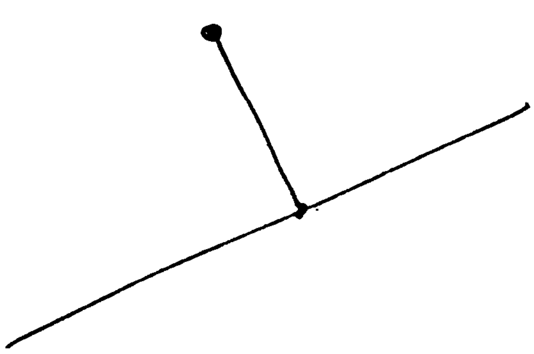
In Algorithmic terms to calculate first set of pairs. (1)

X = XSTART
Y = YSTART.
For number of lines from. 0 to (N-1)
Pair X = X ⟶ ~~These are used as~~ These are result that
Pair Y = Y. ⟶ will be use to generate normal pairs.
(remember to check for vertical & horizontal lines).
X = X + XINCREMENT
Y = Y + YINCREMENT
Next line number.

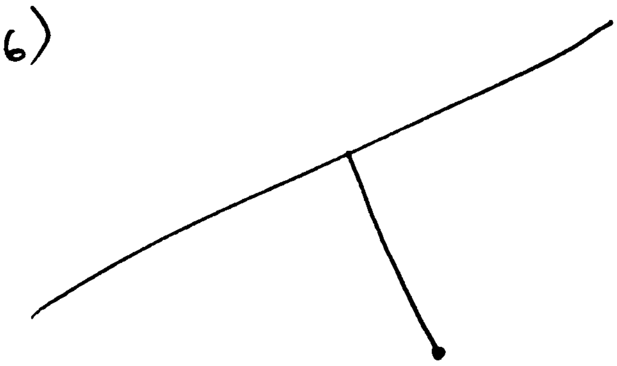
This algorithm can be used to generate the normal pairs.

We can do a normal set in two parts.

a)

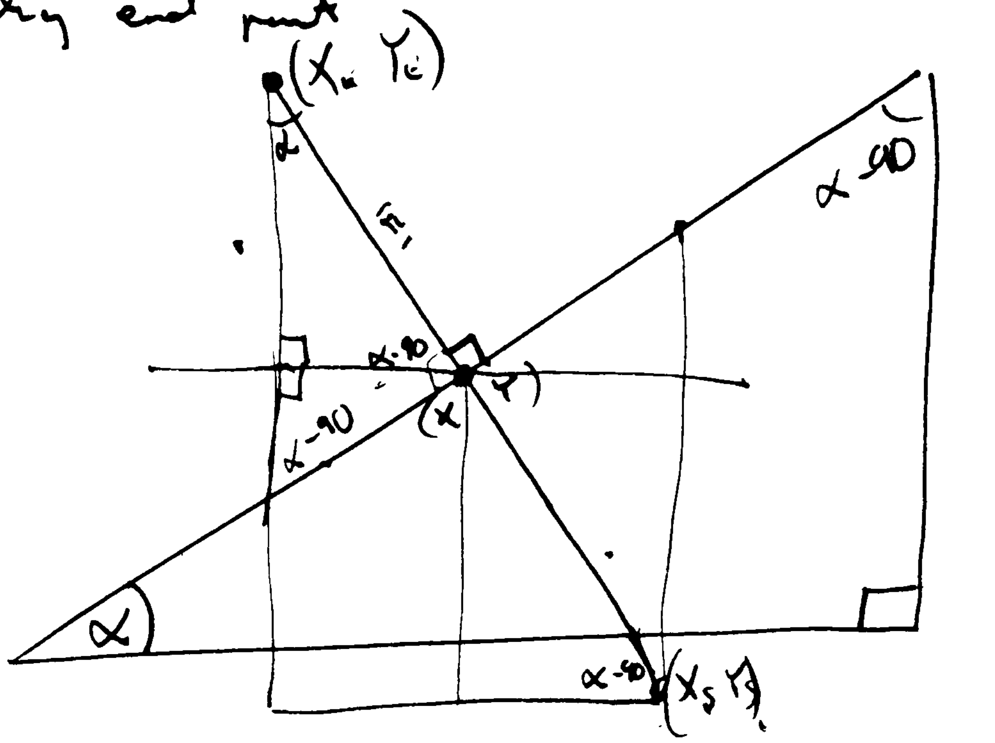


b)



can do this because may be even no of point.

creating end point



$$\cos\alpha = \frac{\Delta Y}{\Delta H}.$$

$$\sin\alpha \cdot \frac{\Delta x}{\Delta H}.$$

we know. l M. So Length. = $l*(M-1)$ &

so dividing $\frac{l*(M-1)}{2}$

$$\Delta y = \cos\alpha \times \Delta H$$

$$\Delta x = \sin\alpha \times \Delta H.$$

$$X_S = X + \Delta x$$

$$X_E = X - \Delta x$$

$$Y_S = Y - \Delta y$$

$$Y_E = Y + \Delta y$$

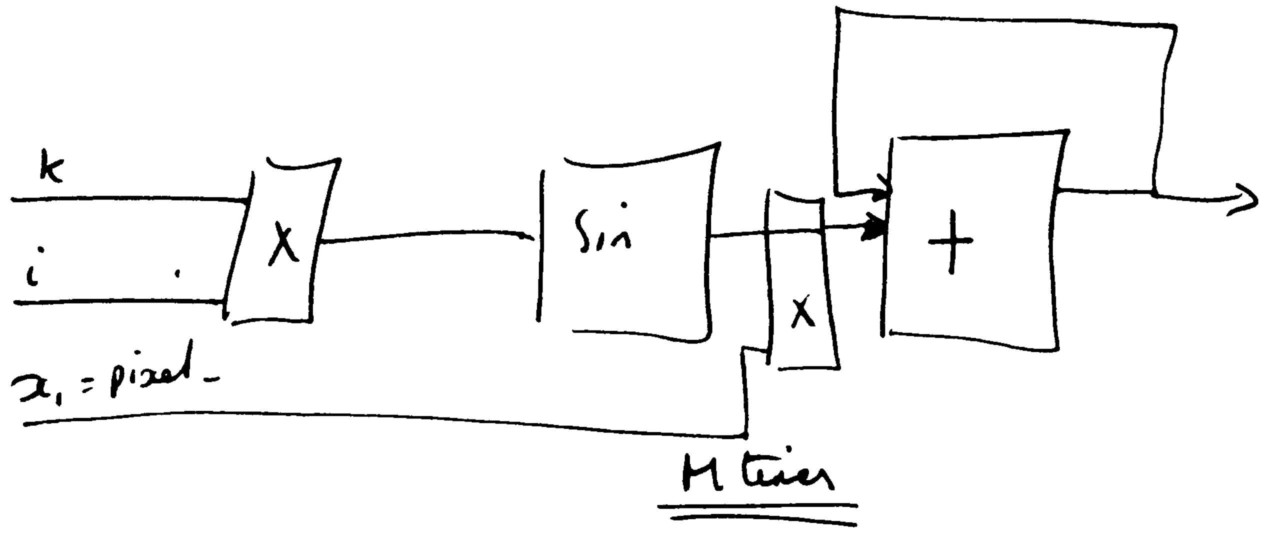
Plug that into Iterative Algorithm (1)

This generates pairs to determining $y(x)$ & $h(x)$

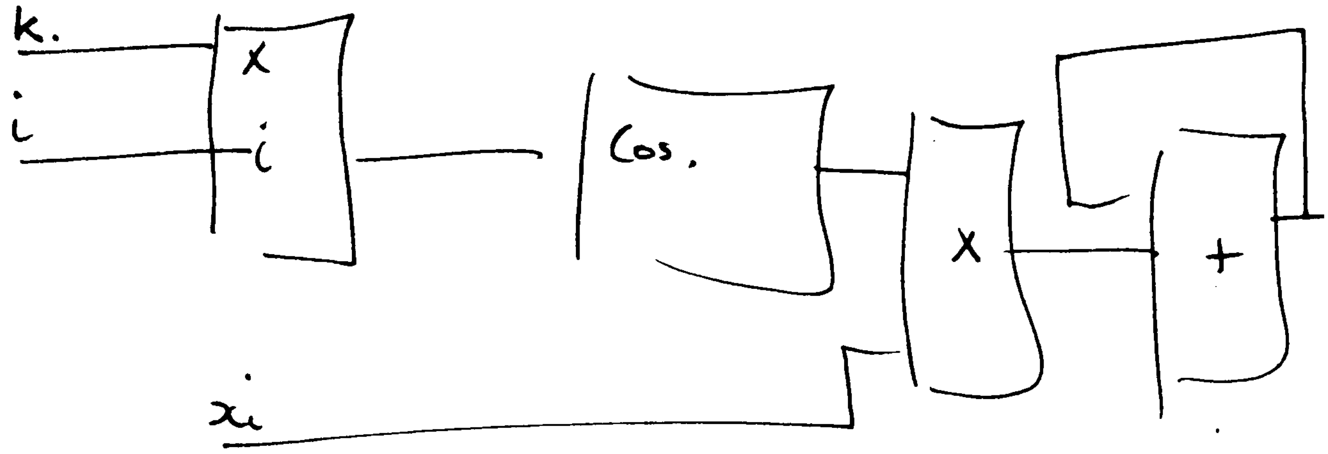
to. ~~[illegible]~~

~~[illegible]~~

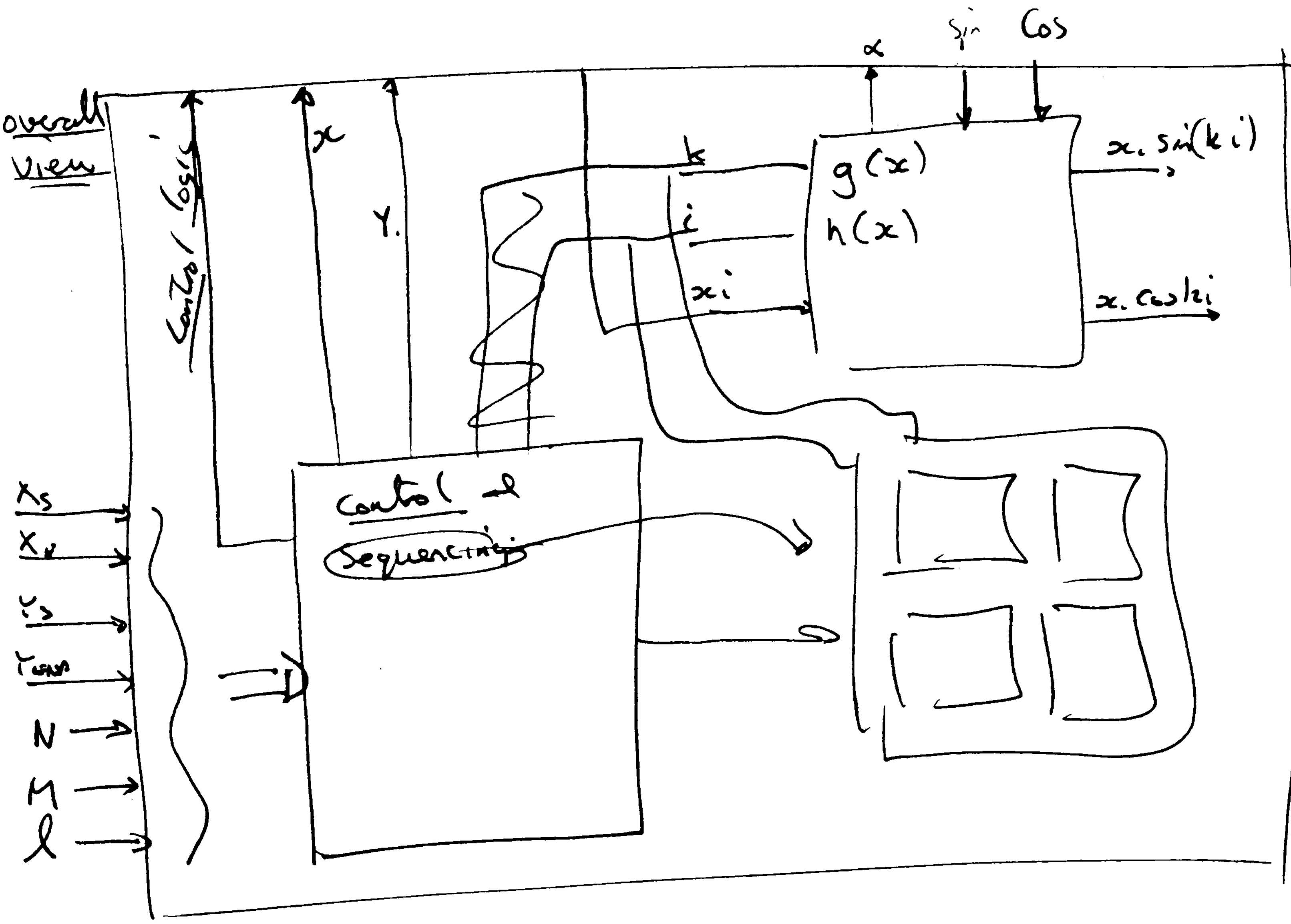
For g(x).



For h(x)



overall view



How to do

- Sin. } lookup
  Cos. } Table

  but Sin Cos are similar (can be derived from one another so only one table, and only need 0 – 45° (or is it 0-90

* OK

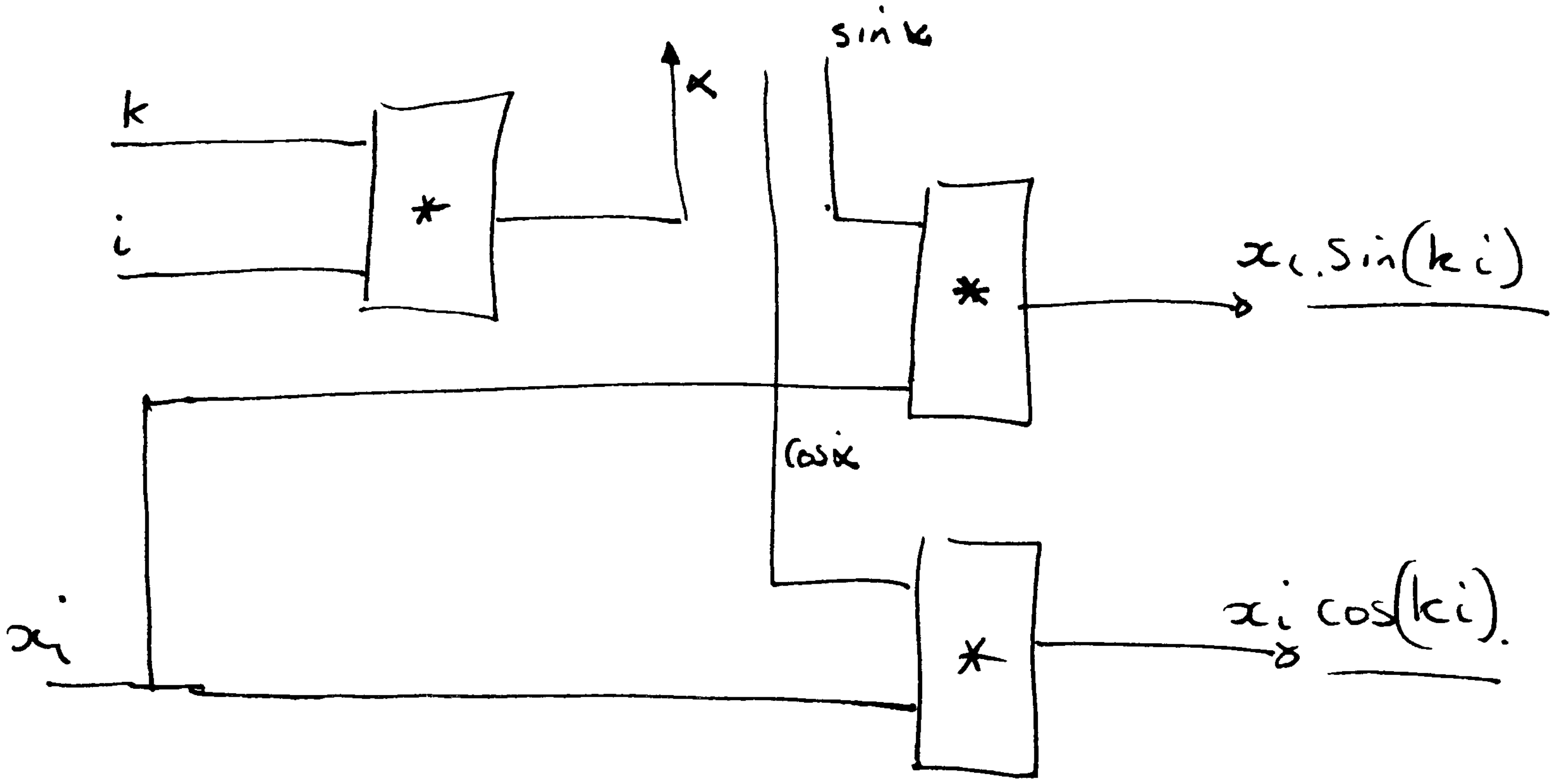
\+ OK.

÷ pain answer is to * $\frac{1}{\text{number}}$.
so reciprocal table and shift.

---

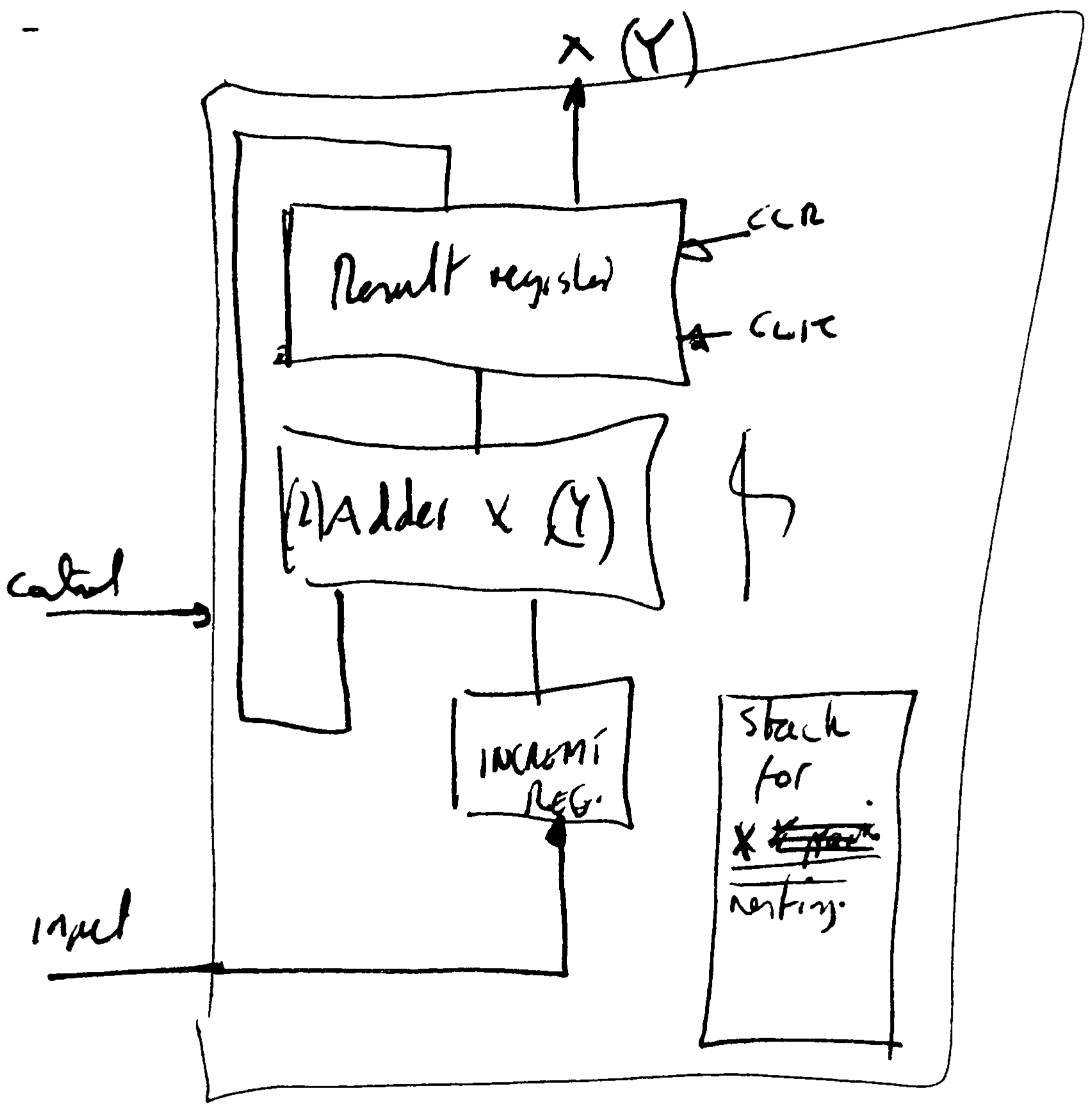
is it going to be flow through ⟶ or engine

g(x) & h(x) are most critical part. so put most of effort there.



Control of Sequencing

duplicate for Y



x 4 for. Outer loop & inner loop.

Control get $\Delta y \div (N-1)$
$\Delta x \div (N-1)$.
put them in.

} decrement and x $(N-1)$

B.2.3. IH'S VERBAL PROTOCOL AND DESIGN WORKINGS

00.00.00
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Process an area of RAM memory ....(unintelligible muttering) .... <Can you start talking in more of an audible tone?> Sorry? <Can you start talking .. soon?>

00.00.51
(EXPLAINING TO INVESTIGATOR) Yeah. OK. I mean it's just I usually read through things myself anyway <OK> It's just when I start, uh, trundling my way through it, I'll <The sooner you start talking the more of your thought processes I can capture> Oh, I see. OK <Just try and talk audibly>

00.01.04
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) Right .... (unintelligible muttering) .... At each coordinate pair.. so derived ... generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .... (unintelligible muttering) .... <Experimenter prompt> ..

00.01.53
(EXPLAINING TO INVESTIGATOR, COMMENTING TO INVESTIGATOR) I'm just trying to work out what we're actually trying to do .. which is apparently a quiet part for me I think... <I'm interested in all those kind of things so ...> OK. Well what I'm doing now is actually trying to go through the thing and work out what the task is .. before I, uh .. start thinking of ways to solve it <Well I'm even interested in your problem definition phase> OK. So, well what I'm actually going to do is, uhm, work out what each of these separate tasks mean and try and picture what I'm trying to do in terms of real things I guess rather than statements on paper .... <Obviously you must be having thoughts going through your head, so .. rather than tell me in retrospect what you've been thinking it is better if you can think aloud> OK. Yes now as you say it's .. it is a bit awkward to get into the way of it <It's quite unnatural in a way> OK .. I'm a quiet person by nature you see, Mr P----- may tell you different. But, uh ..

00.03.00
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) OK. So we're sending two X, Y coordinate pairs .. which define the start and end of the line ... We're sending constants N, M and L. So we're trying to find out what the constants mean .. N coordinate pairs along the line vector <That's it .. that's just what I want> OK ....

00.03.26
(QUESTIONING SELF) So what is M and what is L? ....

00.03.33
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given

line vector ... Using stepping factor L form .. M coordinate pairs ... At each ... So we're dividing the line up by N ... and at each of those points .. generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .. OK. So we're drawing lines at right angles .. Using the stepping factor L form M coordinate pairs .. (unintelligible here) .... M ... At each normal coordinate pair fetch the nearest pixel from memory and summate its value according to the expressions below ....

00.04.47
(QUESTIONING SELF) So what the hell is 1?

00.04.49
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) .... stepping factor L .... along the line vector ... M is 5 .. N is 8 .. 1, 2, 3, 4, 5, 6, 7, 8 .. M is < Can you talk a little louder?> OK. Sorry <I'm not that sure of the sensitivity of the equipment, but you're doing well, that's what I want> Right .. At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .. Using the .. stepping factor L form .. form M coordinate pairs .... Coordinates for a line vector .. stepping factor L .. Form M .. OK. So .. We're breaking the .... At each coordinate pair so derived generate the appropriate coordinates .. Each of the normals is broken up ... into L coordinate pairs .... Using stepping factor L form M coordinate pairs .. So if M .... that's 4 .... Using stepping factor L form M coordinate pairs ..

00.07.20
(QUESTIONING INVESTIGATOR, EXPLAINING TO INVESTIGATOR, COMMENTING TO INVESTIGATOR) Do you know if the variables he's actually specified here relate to the diagram at all? <Yeah> 'Cos he's got N as 8 - which is pretty obvious there are 8 .. there are N.. 8, uhm, normal lines, and then he's got M as 5 <M is 5, yeah> Uh .. So, from what I would guess we're using stepping factor of L. Ah, I see! So L is going to 4 in this case, is that right? <I don't actually know > So we break the .. We have a stepping factor of 4 .. And so they're the M coordinate pairs . Oh I see. I understand now <Yeah?> Yeah, he hasn't actually quoted L in the .. <He hasn't given you a value for L has he> No, it's implied I guess, and there's a squiggle here which is 3 - Which I don't quite understand .. <No that's an M, I'm sorry!> That's an M! Oh, I see and I was taking it as 3. That's fine <I suppose L is the stepping factor along here> That's right so L should be 4 which he hasn't actually given, but, uh .. it's typical C----- If in doubt, don't tell them! ....

00.08.14
(SUMMARISING PROGRESS) All right, that's the problem understood ..

00.08.17
(STATING INTENTION) What we have to do now is work through an example .. and have a look at the calculations that we will actually do on the data ...

00.08.29
(EXPLAINING TO INVESTIGATOR, COMMENTING TO INVESTIGATOR) So .... Yeah, I thought that was a 3 on the side you see <Yeah. I'll make a note of

that> I'll just blame C----- <Also there's one other request. Could you use my black pen because it comes out better on the paper> OK. This is black anyway <Is it?> Yeah <What thickness is it? Can you gave me a squiggle? Oh that will do, yeah> Yeah it's one of these fine point ones .. It's the engineer you see - we use the precision instruments <Yes. You're getting used to the talking aloud a bit now> Yes ... Yes it's, uh.. <As long as you keep the volume up because I have to transcribe all this material afterwards> Right .. You should be taking notes as I'm talking ... <(unintelligible here)> Oh thank you! ....

00.09.48
(STATING INTENTION) Right. So all I've got to do now is decide which is the best way to go about it.

00.09.52
(QUESTIONING SELF) And .. do we put numbers in .. or do we stick with variables?

00.09.57
(UNDERSTANDING INPUTS, UNDERSTANDING FUNCTIONAL REQUIREMENTS, MAKING NOTES) I guess variables would be better .. Uhm .. So .. we have .. start it's going to be .. uhm .. X1, Y1 .. and the .. end will be X2, Y2 ..

00.10.25
(SELECTING SUBPROBLEM, STATING INTENTION) The first thing we need to do is to calculate .. N pairs along the line vector ..

00.10.32
(GENERATING MATHEMATICAL SOLUTION CONCEPT) OK ... It would probably be a good idea to find the length of it, so we can divide it by N ..

00.10.44
(SELECTING SUBPROBLEM) To find the length we need to ...

00.10.51
(GENERATING MATHEMATICAL SOLUTION CONCEPT) Simple old Pythagoras ... So it's going to be ....

00.11.03
(QUESTIONING SELF, EVALUATING MATHEMATICAL SOLUTION CONCEPT) Or is it? .... If .. Is the length going to be of any use? Yes ..

00.11.20
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) The length .... equals square root .. of .. (X2 -X1) .. squared plus (Y2 - Y1) squared ... and then .. divide length ... by .. (N - 1). So the .. separation .. of the tangents ... will equal ... LENGTH over (N ... - 1) ..

00.12.29
(STATING PLAN) So what we need to do now is translate the separation .. into a quantity we can add .. to the starting distance to give us the coordinates .. of each of the coordinate pairs along the vector .... Uhm, pum, pum, pum .... So ..

00.13.14
(QUESTIONING SELF, EVALUATING MATHEMATICAL SOLUTION CONCEPT) Is that of any use to us? ... Yes 'cos (unintelligible here) can work out the angle ... between that and that ..

00.13.34
(QUESTIONING INVESTIGATOR) Is it OK if I scribble on the question paper? <Yeah>

00.13.36
(SKETCHING GRAPHICAL MODEL, STATING PLAN) Right ... Work out that angle which we'll call theta .. and use that to work out ... the .. value to add to X and the value to add to Y ....

00.13.57
(GENERATING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSION) OK. So .... That's going to equal ... Tan theta

00.14.10
(QUESTIONING INVESTIGATOR) Is the pen OK? You can actually see what's there? <Yeah>

00.14.14
(COMMENTING TO INVESTIGATOR) It must be awkward to have to turn the TV upside down to get the picture! <Exactly>

00.14.20
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSION) Tan theta is going to equal ... uhm .. (Y2 - Y1) over (X2 - X1) ... That's right .. That's opposite over adjacent .. So .. Theta equals .. tan to the -1 .. (Y2 - Y1) over (X2 - X1).

00.15.02
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) Real bitch to work out! .... Right ....

00.15.29
(QUESTIONING SELF) How do we relate that to the coordinates which we will call what?? .. N0, 1, 2, 3, 4, 5, N6, N7 ...

00.15.55
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) Got the angle .. so we should be able to . Call that S .. So in terms of S and theta .. should be able to .. decide on .. the values of N ... For .. X equals .. 0 .. through to .. 7 ... (unintelligible here) number .... I'll call it P for want of a better one .... So ... NP (X, Y) .. is going to equal what? The X is going to be - Do the X coordinate first - Is going to be ... X1 - the starting point - plus sine, cosine, cos theta is going to equal the X .. over the hypotenuse which in this case is .. S .. So plus .. plus .. P .... is .. cos theta ... And the Y coordinate is going to equal Y .. from the starting point .. plus P times .... sine theta ....

00.18.30
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, SUMMARISING PROGRESS) So that gives us the coordinates .... That's right.

00.18.42
(STATING INTENTION) Let's try that .... Right .... By graphics we are able to prove that the (unintelligible here) is correct ....

00.19.03
(PROVING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) Wonderfully squared paper! .. And we'll go .. make it easier ... So that's going to be what? .. - Start at 5 for want of a better number .... A vector .. So we want to get tangents there, there, there .. and there .. So in this case.. N, the number is going to be .. 4 .. (X1, Y1) equals (5,5) .. (X2, Y2) equals .. (8,8) .. Right .. So length ... equals square root of (X2 - X1) squared ... minus 5 .. Which without using a calculator is going to be about 3 ... Squared plus 3 squared ... equals root .. 18 .. What is the square root of this? .. 4.24 ... All right. So the S ... is going to equal 4.24 over 4 .... 4.24 divided by 4 .. 1.06 ... All right .. So that's S .. Find out theta ... Tan to the -1 .... 3 over 3 .... 45 .... Quite obvious really! .... So now we know theta and S .. So we should be able to work out P coordinates .. So ... P .. P should be defined in terms of N .... 0 to (N - 1) ... Right. So .. N0 .. N1, N2, N3, ... Drop the X and the Y: equals X1 .. which is .. 5 plus 0 (... 1.06 ... cos 45) ... comma .. Y1 equals (5 .. plus 0 (1.06 .. sin 45) which - as you expect - equals (5, 5) .. Which is right for the first case .. (5 plus ... 1 (1.06 .. cos 45), (5 plus 1) (1.06 .. sin 45) .... That (unintelligible here) what I thought it would ... (unintelligible here) .. That's going to be .... Well, of course it won't! .. Perhaps it should have been 6,6 .. Why didn't it give what I thought it would give? .... No .. it's 3 by 3 .... It should be 1.4 .... Ah! .. 18 .. root .. divided by 3 .. So that should be .. 1.414 - which is right. Just spotted that .. So the calculation here .. which is N - 1. A silly mistake! .. So. 1.414 .. 1.414 .. 1.414 .. OK. Let's do it properly .. (unintelligible here) equals 1 .. Surprise, surprise! .. 6 .. 6,6 .. So that's always going to be 1 .. So ... 7,7, 8,8.

00.27.08
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, EVALUATING PROGRESS) Works for the simple example. Should work for the rest. Right. So we've proved that works .. So there's the example. OK. That proves that the first part works .. (unintelligible here) the calculation to do that which is pretty involved ...

00.27.48
(STATING INTENTION) Draw this on the bottom of here just to keep it on one piece of paper and ..

00.27.54
(SUMMARISING PROGRESS, WRITING MATHEMATICAL EXPRESSIONS) Uhm. So the things I need are ... that .. and that .. Also the fact that P equals ... 0 to (N - 1) .. that gives me the .. relationship at the end .. NP, uh, (x, y) equals .. (X1 + P(S.cos theta)) .... (Y1 + P(S.sin theta)) .. (unintelligible here) we record it for posterity ....

00.29.15
(SELECTING SUBPROBLEM, READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) N pairs along the line vector which we've done .... Right. So, at each coordinate pair so derived .. generate the appropriate coordinates for a line vector drawn at a normal to the given line vector using the stepping factor .. Oh - Using the stepping factor L form M coordinate pairs ... Right. So we (unintelligible word) to divide it that way and find the ends of it ..

00.29.50
(SKETCHING GRAPHICAL MODEL) So now we start off with a ... coordinate ... which is going to be NP ... And from that coordinate we've got to find the start and finish of the line ..

00.30.08
(QUESTIONING SELF) How long is it?

00.30.09
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) It is .... It is .... At each coordinate generate appropriate coordinates ...

00.30.31
(STATING INTENTION) So I'm going to sketch it down ...

00.30.35
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS, SKETCHING GRAPHICAL MODEL) So we've got a line vector which we have .... points .. What are those things we have to generate? - Normals .. to them. ... At each coordinate pair so derived, generate the appropriate coordinates for a line vector drawn at a normal to the given line vector ... Using the stepping factor L form M coordinate pairs .. OK. So we can work out the length from that. That's easy .... So the length .. length of the line .. is going to be in terms of L and M .. So by the looks of from the values given to me on the diagram .. it's ... it equals 5. So there's 5 coordinate pairs ...

00.32.03
(GENERATING MATHEMATICAL SOLUTION CONCEPTS) So the length of it is going to be.. L times (M - 1) ... (unintelligible here) shall we call it .... The length .. (M - 1) .. not divided.. times the length ....

00.32.51
(QUESTIONING INVESTIGATOR) Can I stop it for a second while I go and get a cup of coffee? <Uhm. Yeah you can do if you want> Is that OK? <Yeah, as long as you don't stay away too long> No it's just to pop to the coffee machine

00.33.05
(COMMENTING TO INVESTIGATOR) .... <short break to get coffee> .... Yeah things will start moving now. I'm just trying to .. at the moment. Right. Now I've had the coffee .. As I say, the most important part of a designer's kit is the coffee machine ...

00.33.33
(QUESTIONING SELF) Where the hell was I?

00.33.36
(RE-SELECTING SUBPROBLEM) Right. So we're going to try and find the ends of the normal vectors ...

00.33.46
(STATING INTENTION) I'll just try and check this.

00.33.47
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, SUMMARISING PROGRESS, WRITING MATHEMATICAL EXPRESSION) The length of the normal ... is going to be ... (unintelligible word) M coordinate pairs .... So .. M .. coordinate pairs on the line .. separation of L .. Length of it has got to be (M - 1) times L .... Right. So .. Call .. call that LN equals (M - 1) .. times L ..

00.34.49
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) So derived generate the appropriate coordinates .. OK. So we find the .. we find the (unintelligible word) .. So that's the length ....

00.35.22
(QUESTIONING SELF) Will finding the ends really help us? ....

00.35.35
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) If we have ... the end points - Assume we have the end points .. We need to divide it into ... L segments .. So we already know the stepping factor. So it's bound to be an integer number .... (unintelligible here) rotated ....
<Experimenter Prompt>

00.36.34
(EXPLAINING TO INVESTIGATOR) Yes. Yes things are starting to .. I'm just trying to think of the actual implementation of it now and thinking what a bitch it's going to be. See if you rotate the thing, everything I've written so far I think goes out the window 'cos I've assumed that one point is ahead of the other ..

00.36.48
(QUESTIONING SELF) Or have I? ....

00.36.59
(COMMENTING TO INVESTIGATOR) I think we've got a situation where the mouth swaps out when the brain is really working! .. A true multi-processing system! .... Never to worry about that. I'm sure it will all come out all right in the end.

00.37.26
(QUESTIONING SELF, GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS) If we're adding .. what we need to know is can that be minus? Can it be negative? Yes .. That can be negative. So ... If start is .. from the end it comes in that way and that will follow. So really that needs to be refined before we move on

.... because .. we step out that way .. that's fine .. But if we're going to start at that end ... Can easy swap them over .. What if we go that way? .... (Unintelligible here) will be positive 'cos we're squaring .. Theta will be .... You get a negative number there ... That should (unintelligible here) - Assume it does for now ..

00.39.02
(STATING INTENTION) Can't be arsed to work through it! ...

00.39.09
(QUESTIONING SELF) Right .. What do we need to do with this? We have .. OK. Assume we have the end points .. Will that help us work .. work (unintelligible here)? .... Does it matter which way they've got to come? We start at the bottom ....

00.39.44
(COMMENTING TO INVESTIGATOR) 90 minutes already? .. Oh I was going to say .. <Not long at all actually> Really <About half an hour because some of the tape was occupied by someone before> Oh I see .. This must be one of the most boring home video you've ever made! ....

00.40.14
(SUMMARISING PROGRESS) So we know the end points ..

00.40.22
(QUESTIONING SELF, SELECTING SUBPROBLEM) What's the best way to move up and down and generate the coordinates?

00.40.47
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL) We'll start .. We'll start at one end or the other ... depending on .. the .... L. So in terms of L we should be able to define - Make it nice and easy if we can - .. Say that is L .. We know .. that angle is theta .. So that is going to be ... 90 minus theta .. So .. phi ... So that's phi .. That .. is going to be theta .... So simply we should just step up the line ..

00.42.19
(STATING INTENTION) Let's try it ..

00.42.23
(QUESTIONING SELF) In this case - Where's the example? ...

00.42.28
(PROVING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSION) (unintelligible here) a grid .. So if we start at, uhm ... the same .. the same point again .. If we start at .. 8,5 and - What's that way? - 5,8 .... So I'm not going to have any problems with that thing as well .... So .. do we use this one? (unintelligible here) going to be 8 + 1 times (L.cos phi).

00.43.56
(QUESTIONING SELF) Is that right? ....

00.43.59
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) If that's at 45, that's going to be 45 .... Cosine ... We want really the answer to be .. minus 1 ... So cos plus phi .... So that's X ... that's going to have to be minus if that's going to be positive ... 135 ... So if I always use that angle ... Assume that's a positive contract .. Always measure from that angle. That will work ...

00.45.26
(QUESTIONING SELF) OK. How am I going to get back into that one? ...

00.45.33
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) Surely by doing that .. I'm always going to measure .. that angle .. OK and this one .. Seeing that one's OK - It looks as though it's going to be .. (unintelligible here) .. Uhm ... So we say we're going to say we're going to use that angle ... So that is going to equal .. if I call that phi (unintelligible here) that ... It's going to be theta minus 90 .. In this case because I've moved it around, phi equals theta plus 90 ....

00.46.50
(STATING INTENTION) So now we'll put the numbers in and see .. see what happens ..

00.46.58
(PROVING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSION) So before, I got .. theta as 45 .. So phi is going to be 135 as we said .. So .. 135 Cosine - Which is right - times 1.414 .. plus.. minus 1 ..

00.47.16
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL) So .. working back up the line I've got to use .. the original theta .. which takes into account the relative positions of X and Y .. Stick with theta (unintelligible here) .. So the positions for the coordinates along that line are going to be .. - What do they call them? - .. Just coordinate pairs .. So it's going to be a function of .. a line ... A coordinate pair .. associated with .. each line .. (unintelligible here) start and finish points - Is going to be ... X, Y .. It is going to be the same as before .. In this case we've got .... Can we assume that .. is (unintelligible word)? ... So we know the length of a (unintelligible word) so we can .. take it away and add it .. So we can work on the principle that we know which was the worst ..

00.49.04
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) (unintelligible here) .. coordinate N top and bottom .. NX bottom plus (unintelligible word) L .. So .. (unintelligible here) So I need a counter anyway .. So that's 0, 1, 2, 3, 4 .. It's (M - 1) .... Uhm .. M equals (M - 1) .... M equals 0 to (M - 1) .. And we have .. M times .. (L - That's the length rather than S it was before .. cos phi) .. Or in the case of the Y coordinate .. NY .. bottom plus (M ... L sine phi) .. (unintelligible here) .. Then just to finish it off just stick another bracket on ..

00.50.56

(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) And that should give us the coordinates of each of those points along the line .... There's no reason why we shouldn't (unintelligible here) that ... and that .... and that .. Should be OK .. So I can produce the coordinates of the .. L spacing

00.51.38

(SELECTING SUBPROBLEMS, STATING PLAN) Right what we need to do now is to deduce the .. original coordinate NP ... and the length LN .. to determine the end points ....

00.52.04

(SKETCHING GRAPHICAL MODEL) So we have .. a point on the line .. which is going to be NP .. (x, y) .. and we know that line is .... LN long .... LN equals L times (M - 1) ...

00.52.47

(QUESTIONING SELF) What's the easiest way to calculate the end points? ..

00.52.53

(GENERATING MATHEMATICAL SOLUTION CONCEPTS) Guess .. to subtract .. half of it and add half of it .. Patently obvious ..

00.53.06

(QUESTIONING SELF) So how's that work in practice? ..

00.53.11

(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS) If I know the length .. Does it matter? .. Yes, I need to know what angle it is .. I still know theta .. So if I put a line through there we know that is going to be phi .. So if I add half of it in direction phi .. subtract half in the same direction ...

00.53.47

(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) That will make a nice .. No it won't!.. It will ... be about right ....

00.53.56

(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL) Right now that .. is our line .. Now that point there is NP(x, y) .. And this .. is our tangent .. And that angle is phi .... That is .. phi .. We need to know the .. x and y .. values .... there .. and there .. Which happens to be theta ... Yes theta .... So if that .... is half .. What shall we call it? .. NL .. Oh .... Of course, it's going to be a cosine .. equals cos ... NLx over .. is going to equal .. It would be .... over hypotenuse which is NL .. NL Cos theta .. We know y equals NL Sine theta ... So to find the end points .. There's something .. (unintelligible here) .. It's got to be theta .. We haven't got a square root .... So the end .... the end points .. Which we can call what? .... That's going to be .. We'll change those around .. B there .. N .. x .. N .... NB .. bottom x .. N bottom y .. So N top .. will equal .. Presumably that's going to .. going to be positive .. theta .. Going to have to use phi to make sure that that comes out negative .... What do we do in that case? .. Just the same as we did there .. Do exactly the same thing .. The top is going to equal .. NP .. x plus ... that's going to have to be phi .. Or is it? ....

00.59.56
(COMMENTING TO INVESTIGATOR) <Experimenter prompt> .. Yes .... The minute you say that I shut up! I'm suddenly aware that I'm talking to myself .. The first sign of insanity is people talking to themselves I'm told .... The second sign .... The first sign is when someone start's answering back ....

01.00.30
(QUESTIONING SELF) Right .... Is this right or is it a load of bollocks? ..

01.00.42
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSION) If we use phi .. In this case phi is going to be right .. because that's going to be 135 .. should give us the minus we need .. It's going to have to be phi .. Change that to phi .. (unintelligible here) later .. So that's NLx ... and that's going to be (NPy + NLy) .. N bottom .. (NPx - NLx) which in this case means adding something to it .. and (NPy - NLy) .. So that gives us the top and the bottom which we assume we could get here .. call them .. NB ... That line length with that .. So then that gives us each of the coordinates along the line ... So if we have each of the coordinates on the line .. - which I would guess we have from that - .. We can have .. That would generate .. from ... the end point there .. from that point .. We know length .. So if we know length ... That should be NL over 2 .. Knowing the length we can find .. the vector distance to add .. got to keep pointing that way .. Can use that angle all the time .. That way will be correct .. I hope .. So if we now use that angle .. NL over 2 .. comes out.. should give us in this case .. minus 1 in each case .. or a negative distance that way .. which when we subtract will be a positive distance .. That's sine .. Sine is going to be plus in that quadrant .. Yes it is .. That's right we're going up .. We go up but we still go back. So that's right it is phi .. And phi is still .. 90 plus theta because we turn through 90 degrees ..

01.04.10
(EVALUATING MATHEMATICAL SOLUTION, SUMMARISING PROGRESS) So this looks pretty hunky dory! .. We know NLx and NLy .. NLy .. So from that we can find NT and NB .. which are NT .. NB .. and that one there is NP .. Seems about right .. OK .. So we've got that .. (unintelligible here) ..

01.04.51
(STATING INTENTION) OK. So I can stick that up there ..

01.04.54
(TIME-FILLING VERBALISATION) We don't really need that 'cos I copied that (unintelligible here) .. over with the rest ..

01.05.07
(STATING INTENTION) Right. Let's have a look at the next stage that Mr

C-----'s little mind has dreamt up ..

01.05.18
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) At each normal .. coordinate pair .. each normal coordinate pair fetch the nearest pixel from the memory and summate it's value according to the expressions below .... So the nearest value must mean that .. obviously we're working with integer arithmetic .. I will take a modulus of the .. points we generate along that line .. If we take the modulus that means we always going to get the nearest pixel .. Right .. At each normal .. fetch the nearest pixel and summate its value according to the expressions below generating two data items for each normal vector .... So ... at each point on that line .... we fetch the nearest pixel from memory .. and summate its value according to the expressions below .. generating two data .. So each value we take the actual data .. xl is the current pixel .. Take the data .. times i .. Sine (unintelligible here) .. Take the sine of k ... which will be 360 over M .. There's the number .. Bloody stupid thing to do! .... Picks out each of those points, so we multiply that ...

01.08.02
(QUESTIONING INVESTIGATOR) He says design an integrated circuit - What sort of length does he mean - does he want us to go to? <Well not right down the hierarchy to gate level but maybe a few block> a few blocks of ..

01.08.17
(COMMENTING TO INVESTIGATOR) Right. That's OK then .. It would be much easier to write a high level program to do this you see and go for automatic logic synthesis .. But of course you see this is what we do anyway! .. OK ... A few drinks C----- owes me for this! <Yes> .... Right ..

01.08.47
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) It's plainly obvious what each of those is doing ..

01.08.51
(STATING INTENTION) So now we can start looking at the hardware ..

01.09.03
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) Put them in order .. The first thing we do is .. If we assume that we don't .. (unintelligible here) data elements .. we have elements to do each calculation rather than .. an arithmetic .. which we program .. with a microprocessor .. C----- wouldn't want me to design a microprocessor ..

01.09.40
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) OK. So we're going to .. I've got 1, 2, 3, 4 .. 7 values .. (unintelligible here) to register the values .... So that's going to be able to (unintelligible word) them .. X1 .. and Y1 .... X2 .. Y2 .... That needs to be ... N, M and L .... which are going to ... come in from our generous host .. Right. So we now have to do the (unintelligible word)

calculation .... we get (unintelligible here) .. which is .. so we need to divide it by minus 1 .. P .. theta .. So we just (unintelligible here) .. have ... a block .. which will take in those .. those .. and that .. and out will come coordinates (unintelligible here) .. pass into a Register File .. which is going to be .... N0x, N0y .. N1x, N1y down to.. what do we count to .. N(N - 1)x, N(N - 1)y .. (unintelligible here) .. That's going to be.. what shall we cal it? .. Generate coordinate pairs .. So that gives us the Register File .. down there .. Right .. So that's going to implement that sheet .... The next block is going to have to act upon the Register File .. and .. generate .... the normal ...

01.15.42
(QUESTIONING INVESTIGATOR) Are you wanting to change the tape over? <Yeah, it's all right. Keep working>

01.15.47
(COMMENTING TO INVESTIGATOR) OK .. I've nearly finished actually .. at the level I'm going to take this to .. I'm going to put something in the block, don't worry! .. We have a system next door actually that you can put something like this together very quickly. You can actually map the mathematical functions onto a little block. So you just feed the two inputs in and pop say a tangent of x minus y or whatever <In our system we're trying to allow for mathematical manipulation and function evaluation> Well the idea of that is that you build up your algorithm and refine your algorithm to what you want it to be .. and then continue refining it and adding detail which refers to the way in which you actually implement it in terms of the bus widths et cetera. Then you reach a point where you have models of things which are represented in hardware, which you've already built. So you simply then process it into macros which have already written. Then you produce your integrated circuit. So you work from a concept level .. take it down to a level which somebody else has already designed the cells .. You have a library of multipliers, a library of adders.

01.16.54
(APPLYING KNOWLEDGE OF DETAILED HARDWARE CONSTRAINTS TO ABSTRACT HARDWARE SOLUTION CONCEPT) Dividers are awkward .. but I'm going to put divisions in and I'm going to leave them in .. Divides are nasty ....

01.17.02
(SUMMARISING PROGRESS) Right ... Right so we have Register File .. which has got each of the coordinate pairs inside it on the main line ..

01.17.08
(SELECTING SUBPROBLEM) So what we need to do to them now is to produce the tangential vectors .. We need to produce the end points

01.17.26
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Which is done down here .. So we tale NL .. LN .. Then what we need to do is .... drop those into ROM there .. What do we do .. L .. (M -1) .. (unintelligible here) .. LN .. So we have LN .. I've changed it to NL

there just to add to the fun .. It is the same thing isn't it? .. The length of a normal .. Right .. So from that .. Where's phi come from? .. Phi's theta over 90 .. (unintelligible here) theta ... So (unintelligible here) .. output .. theta .... And this one will also do ... phi .. equals 90 .. plus .. theta ... That gives me theta doesn't it? So that gives me: phi, LN which we need ... So from those we can actually produce the top and the bottom points .. for each of these .. So then we take all of those and we ... generate ... NT .. NB .... which is going to give us another .. Register File .. which is in fact square .. - As all Register Files really are .. 4 wide .. And in this we're going to have .... NT0x .. NT0y .. NB0x .. NB0y .. up to NT(n-1)x .. NT(N-1)y .. with NB(N-1)x .. NB(N-1)y ... So tha gives us a Register File .. with, Uhm .... with the coordinates of the tops ad the bottoms of the tangents .. which is what we then pass into that stage .. That goes up there ... I've got LN .. So we just need L and M .. little m .. So we then pass .. that .. pass .... L and M we need .. M and we need L as well .... So I bring .. M .... and L .... down here .. into this block .. which is going to generate the coordinate pairs .. of the tangents .... Generate .... coordinate pairs .... tangents .. just that equation there .. Over each of those coordinate pairs ...

01.24.44
(SELECTING SUBPROBLEM, READING PROBLEM SPECIFICATION) Then we do this calculation ... Fetch the nearest pixel from memory and summate its value according to the expressions below ....

01.25.00
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) So from M .... For each coordinate pair along that line we access the pixel ... quite simply .. (unintelligible here) equation .. So this is going to generate an array of values .. So for each .. N times ... another array of coordinates .... which are going to be ... take these .. CP0x, CP0y .. CP1x .. CP1y .. down to CP.. (N - 1)x and CO(N - 1)y .. and we're going to have ... - Times How many? - N .... So that comes out of there .. This also needs to know M .. So we need to .. generate another box .. which is .... Generate g(x) .. and .. h(x). Feed the results table into there .. and also k.. M ... gets M as well ... That is going to produce ... a g(x) .... h(x) .. 0 .. g(x)1 .. h(x)1 .. g(x)N - 1 ... h(x)N - 1 ..

01.29.03
(SUMMARISING PROGRESS) Right. That's the system .. Four blocks ....

01.29.13
(SELECTING SUBPROBLEM) Generate the coordinate pairs .. It's that equation there ..

01.29.20
(MAKING NOTES) This is .. Generate .. coordinate .. pairs .. Which is .. sheet 8 ..

01.29.44
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS) Right inputs: .. 1, point 1, point 2 .. and

N .. So that calculation there .. So we have 4 values .. Up here we have .. x1, y1 .. x2, y2 .. and then .. Beautifully neat arrows .. Right you need to .. calculate the length which comes from those .. So we need .. Subtractor ... Subtractors .... Squarer .... An Adder ... And a Root ... So (unintelligible here) comes into there (unintelligible here) ..... (unintelligible here) something which we call length ... which we can then .... This is S .... (unintelligible here) .... Oh .... divide .... <Experimenter Prompt>

01.33.34
(COMMENTING TO INVESTIGATOR) Sorry, I'm drawing you see. It's all going down on paper. The diagram is worth a thousand words etc. It just depends who drew the diagram .. and if he was going to say very much anyway .... It's difficult to know what level to take it to actually.

01.33.53
(QUESTIONING INVESTIGATOR, EXPLAINING TO INVESTIGATOR) You know, is it worth me actually drawing out each of the boxes, because it's just describing what's in the calculation anyway. Really most of the work has been done - it's the calculations that I'm actually going to perform .. You know is it worth me going any further to focus on translating these calculations into pictures <Yeah> .. Is it worth doing that .. or would it be better if I just put this in a proper flow and leave it at that .. so you can actually see what I intend to do? <Yes that's probably the best> OK then. So I mean.. <You don't have to take it too far> I've draw it as a system which fits together showing what blocks are passed from what to what <Right> Uhm. But I'm really it's.. it's just changing this.. I'm just changing divide Tan to the -1 instead of writing that, you know. It's not really, uh ..

01.34.38
(STATING INTENTION, EXPLAINING TO INVESTIGATOR) What I'll do is I'll go through and even this up so you can actually see the flow of the, uh.. <Just go a little bit further> the flow of the, uh, design ....

01.34.57
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSION) All right .... Generate coordinate pairs .... Length equals square root of (X2 - X1) ..

01.35.27
(EXPLAINING TO INVESTIGATOR) Yes that's why I'd stopped talking - because I'd stopped thinking, I was just copying <Yes> ..

01.35.34
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) (Y2 -Y1) squared .. which gives us the separation of tangents .. S .... Length .. over (N - 1) .. And we can say that .. theta .... equals .. (Y2 - Y1) over (X2 - X1) .. Tan to the -1 ... So for ... P .. equals.. 0 to .. (N - 1) ..the array of M points .. N subscript P .. equals ((X1 + P(S Cos theta)) ... (Y1 + P(S Sin theta))) .. Which is the array that we pass out there .. That's one result .. and the other result at that block .. - Sheet 9 - .. is that phi equals 90 .. plus .. theta .. So there's your results out of that block ... Then we go to .... Ah .. That's not done ..

01.38.05
(QUESTIONING SELF) Should that be done there or in that? .. Does it really matter? ....

01.38.24
(SELECTING SUBPROBLEM) Right so on to the sheet 10 .... Generate NT and NB pairs ..

01.38.40
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSION) Then that one .. will wrap through those .... These are all part of the solution .... That's the one I want .. We can say that we take in that .. we take in phi and LN .. So .. NLx equals NL, which you bring in from the top .. LN it is .. over 2 .. equals Cos phi .. And NLy ... equals LN over 2 Sin phi ... You can generate points by saying that NT - that's the counter .. (unintelligible here) tops and bottoms .. equals NP .. NP .. (NPx + NLx), (NPy + NLy) ... (NPx - NLx), (NPy - NLy) .. And P equals 0 to (N - 1) ..

01.41.23
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) And that will give me .. (N - 1) .. NTs and NBs .. Which is that result there ..

01.41.35
(STATING INTENTION) Check that one ..

01.41.38
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) That will give me P pairs or (N - 1) pairs which is right .. So the result there ....

01.42.00
(SELECTING SUBPROBLEM) Right ... So generate tangents, which is going to be sheet 11 ..

01.42.20
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSION, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS) And we say .. coordinate pairs of tangents, which was that one .. We've already done that .. So we can say that coordinate pairs on tangents .. For each tangent ... So for each .... row .. of .. previous .. table .. ie .. each .. value .. of ... N .. on the table .. Cp equals .. ((NBx + M .. (L Cos phi)) .. NBy .. - What's the point of working out the top one? .. It didn't help at all - (NBy + M(L Sin phi))) ... Right. So that gives us .. N times that .. which is that table there .. And then each .. for M equals 0 .. to .. (M - 1) .. So for each of those .. we do a simple calculation .... Then ... use table to do look up ..

01.45.47
(EVALUATING PROGRESS) Right. I think that is it ..

01.45.49

START – (X_1, Y_1)

END – (X_2, Y_2)

LENGTH = $\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$

separation of lengths = $\frac{\text{LENGTH}}{(N-1)} = S$

$\text{Tan}\,\theta = \left(\frac{Y_2 - Y_1}{X_2 - X_1}\right)$

$\theta = \text{Tan}^{-1}\left(\frac{Y_2 - Y_2}{X_2 - X_1}\right)$

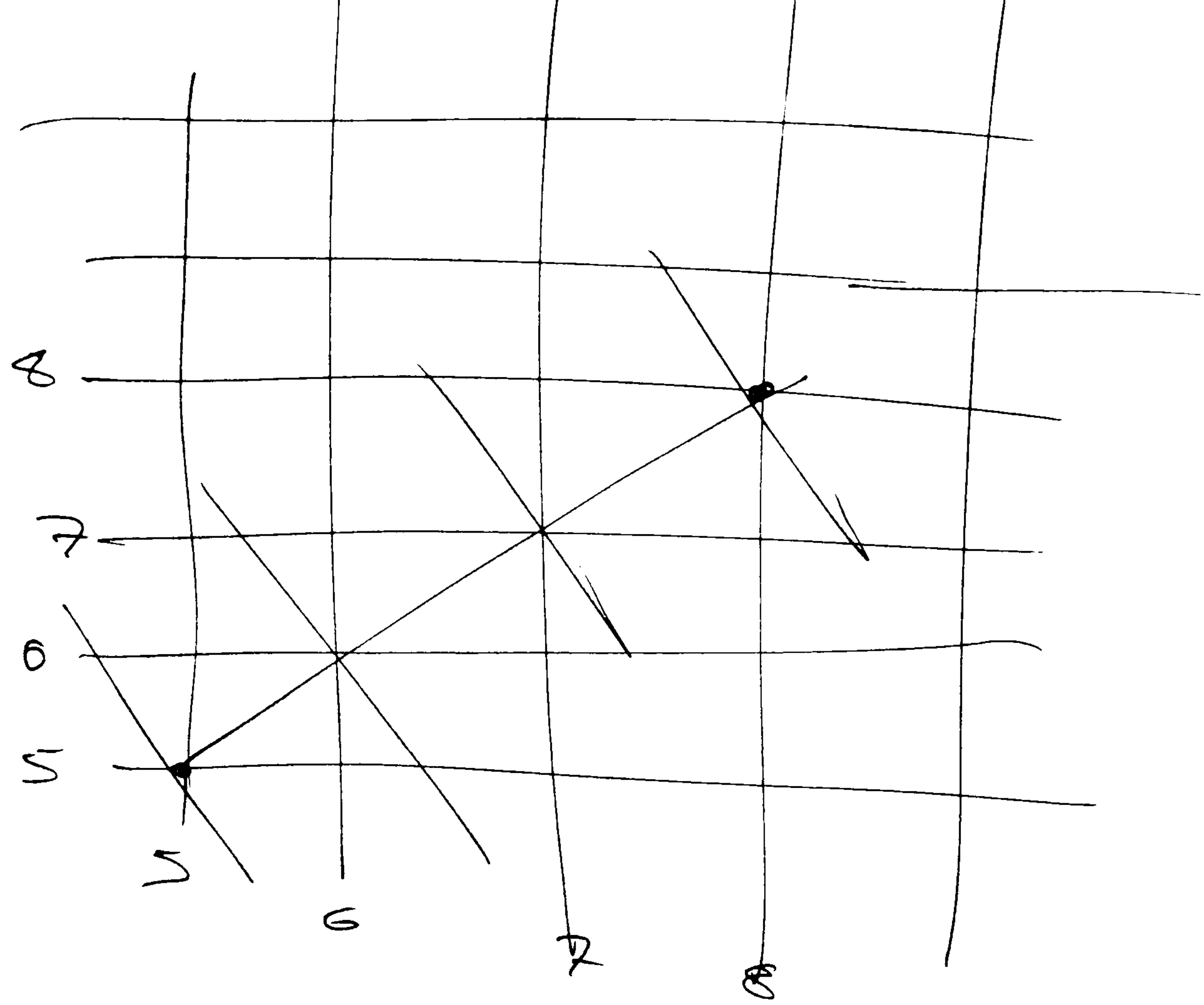
$P = 0 \,..\, (N-1)$

$N_p(x, y) = \left((x_1 + p(S\cos\theta)), (y_1 + p(S\sin\theta))\right)$

$$\rho = 0 \ldots (N-1)$$

$$\cos\theta = \frac{x}{s}$$

$$N_\rho(x, y) = \left(x_1 + \rho(s \cos\theta),\; y_1 + \rho(s \sin\theta) \right)$$



$N = 4$

$(x_1, y_1) = (5, 5)$

$(x_2, y_2) = (8, 8)$

$$\text{Length} = \sqrt{3^2 + 3^2}$$
$$= \sqrt{18}$$
$$= 4.24$$

$$\theta = \tan^{-1}\left(\frac{3}{3}\right)$$
$$= 45^\circ$$

$$S = \frac{4.24}{(4-1)}$$
$$= 1.414$$

$$N_0 = \big(5 + 0(1.64 \cos 45^\circ),\ 5 + 0(1.64 \sin 45^\circ)\big)$$

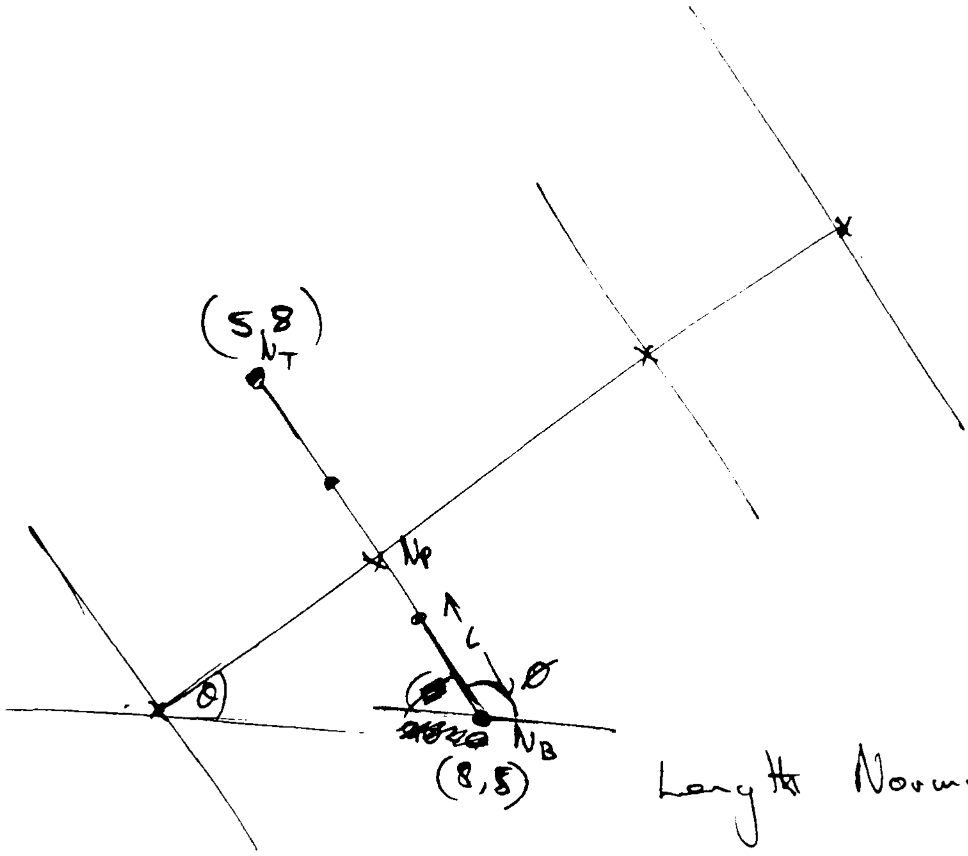
$$= (5, 5)$$

$$N_1 = \big(5 + 1(1.64 \cos 45),\ 5 + 1(1.64 \sin 45^\circ)\big)$$

$$(6, 6)$$

$$N_2 = (7, 7)$$

$$N_3 = (8, 8)$$



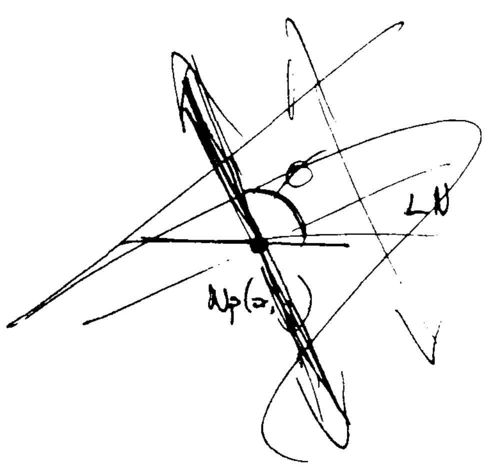
$$\phi = 90 + \theta$$

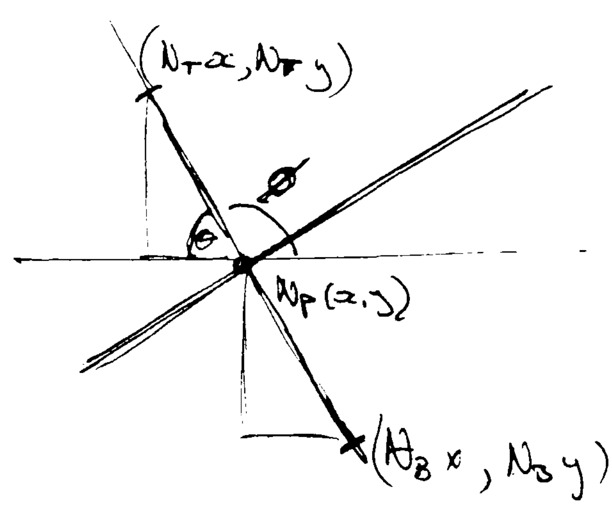
Length Normal $= (M-1)L$

$LN = L(M-1)$

$M = 0 \,..\, (M-1)$

$$CP_{(x,y)} = \left(\left(N_{Bx} + M(L \cos\phi) \right), N_{By} + M(L \sin \phi$$



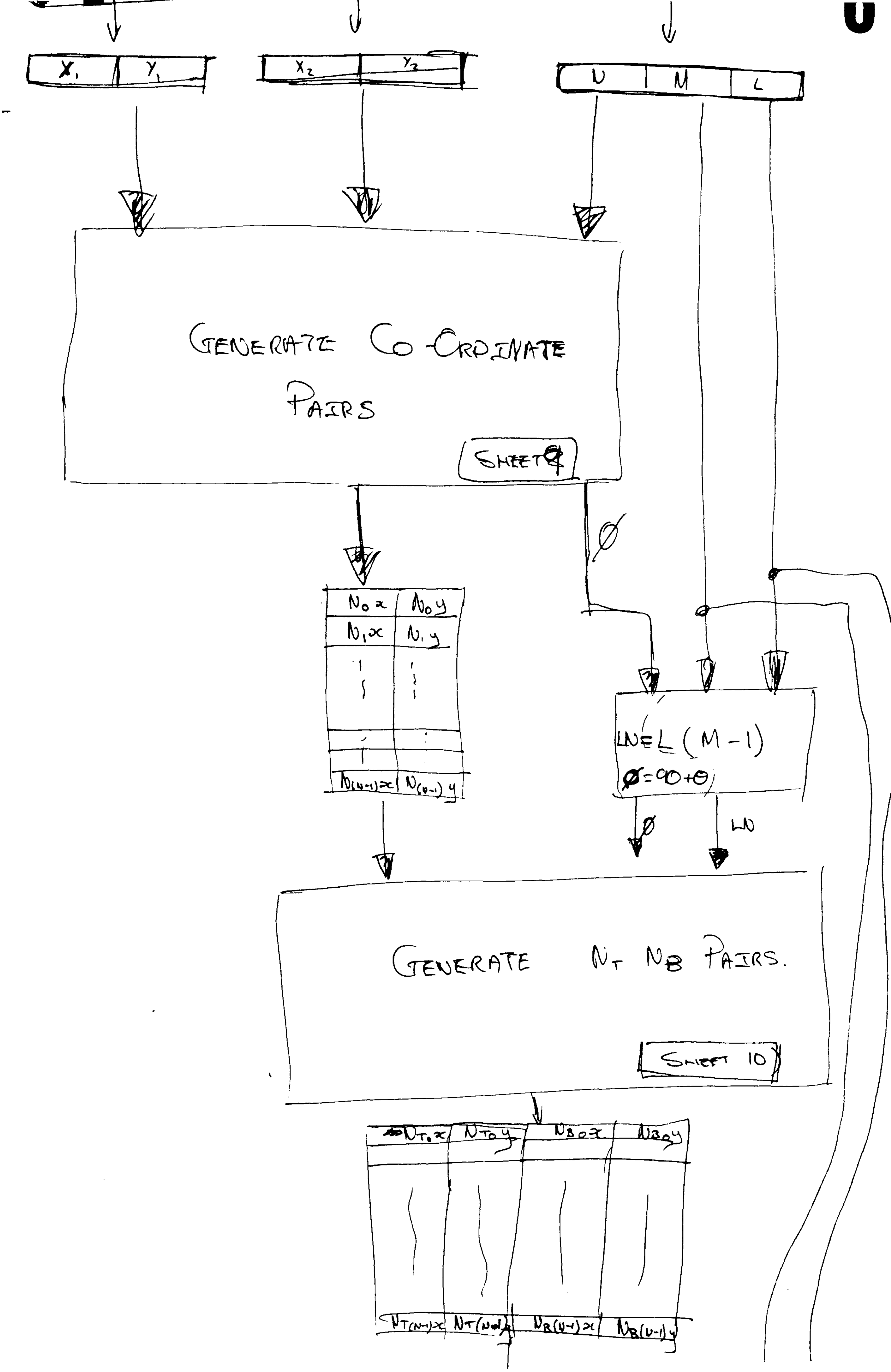


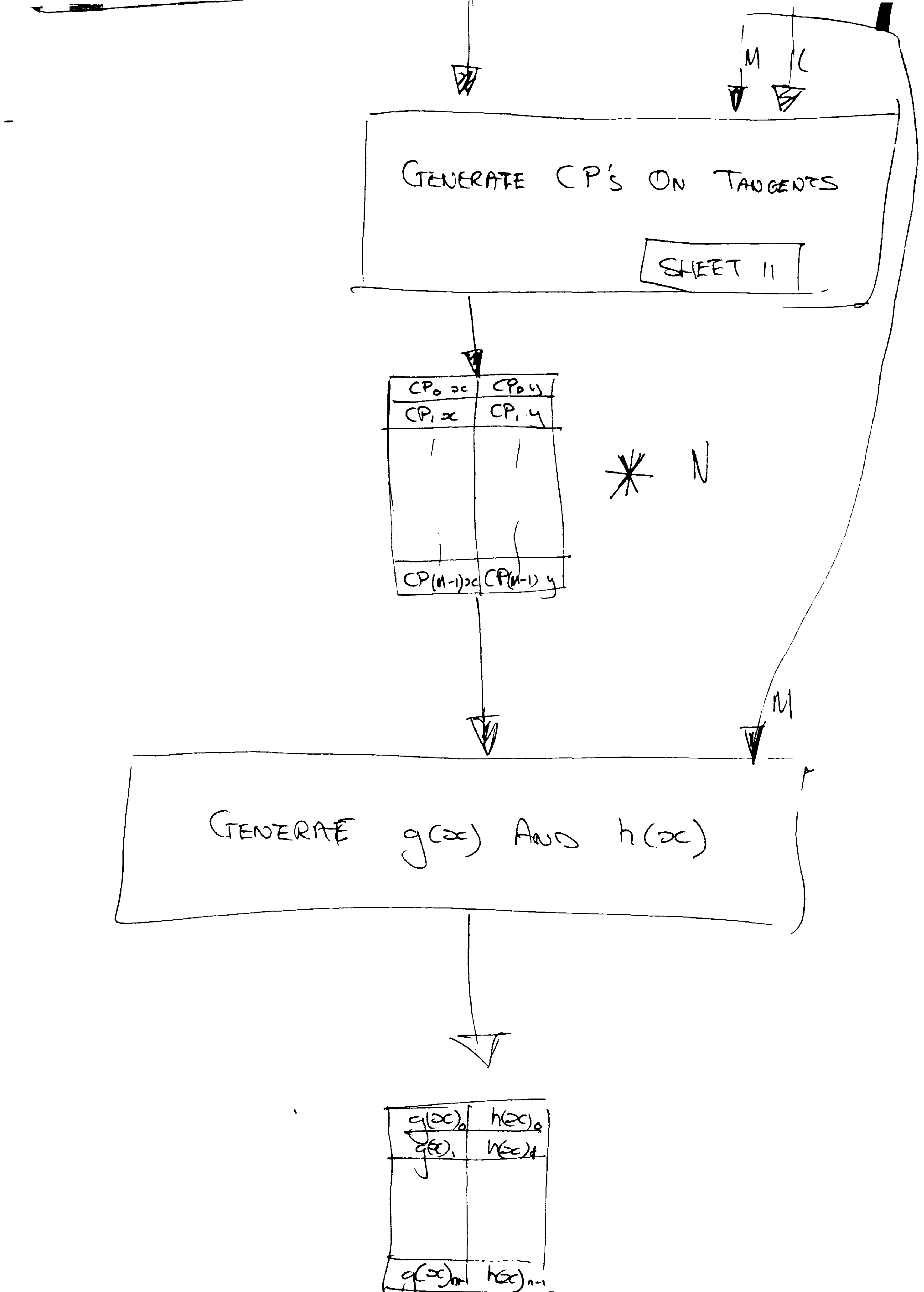
$$N_T = \left((N_P x + N_L x), (N_P y + N_L y) \right)$$

$$N_B = \left((N_P x - N_L x), (N_P y - N_L y) \right)$$

$$NL_x = \frac{NL}{2} \cos\phi$$

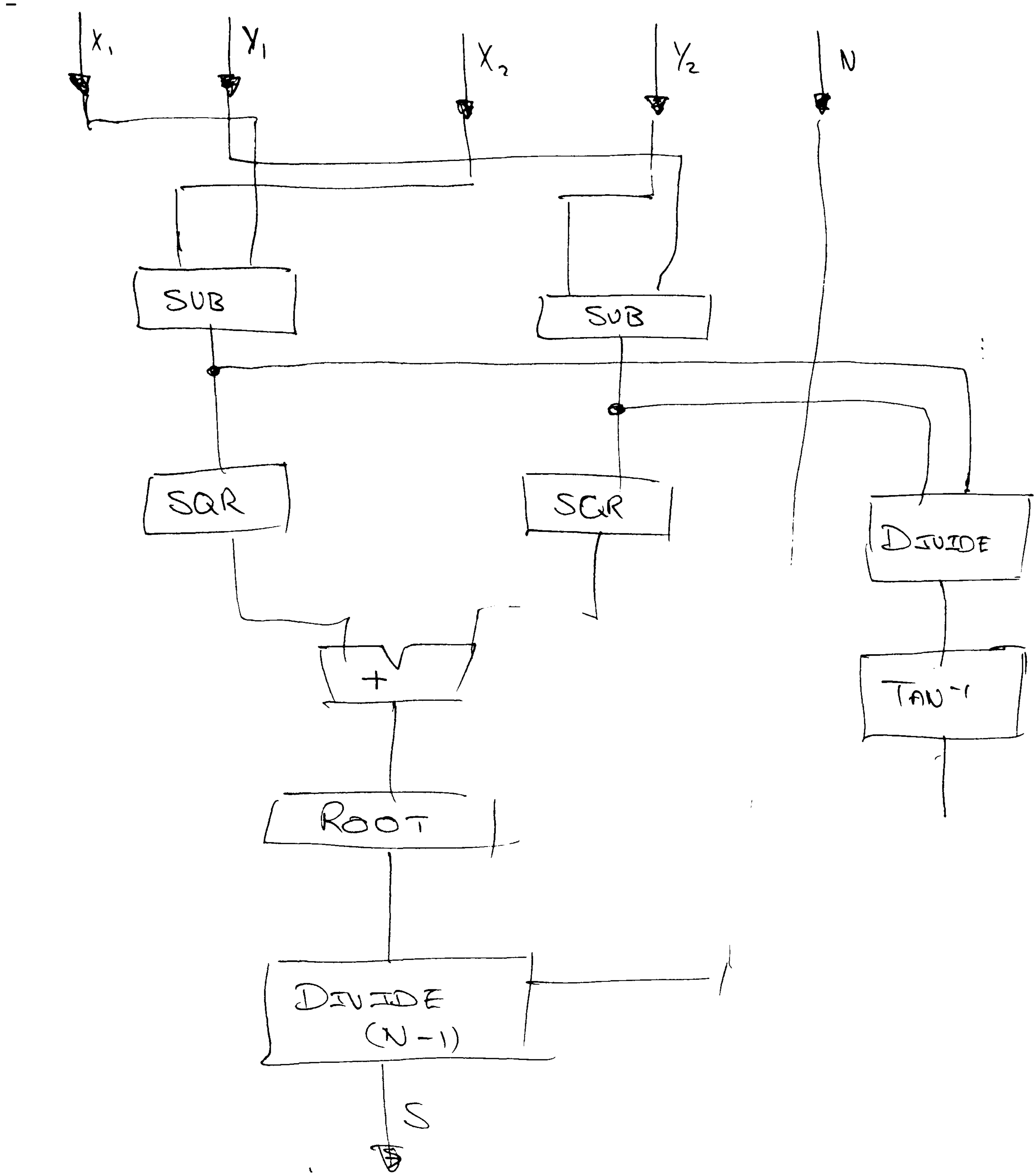
$$NL_y = \frac{NL}{2} \sin\phi$$


X1 | Y1
X2 | Y2
N | M | L
GENERATE CO-ORDINATE PAIRS
SHEET 9
Ø
N0x | N0y
N1x | N1y
N(N-1)x | N(N-1)y
LN=L(M-1)
Ø=90+θ
Ø
LN
GENERATE NT NB PAIRS.
SHEET 10
NT0x | NT0y | NB0x | NB0y
NT(N-1)x | NT(N-1)y | NB(N-1)x | NB(N-1)y


M
L
GENERATE CP'S ON TANGENTS
SHEET 11
CP₀ x
CP₀ y
CP₁ x
CP₁ y
CP(N-1) x
CP(N-1) y
N
M
GENERATE g(x) AND h(x)
g(x)₀
h(x)₀
g(x)₁
h(x)₁
g(x)ₙ₋₁
h(x)ₙ₋₁

GENERATE CO-ORDIATE PAIRS

8



$$\text{LENGTH} = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$

$$\therefore S = \frac{\text{LENGTH}}{N-1}$$

$$\Theta = \tan^{-1}\left(\frac{Y_2 - Y_1}{X_2 - X_1}\right)$$

$$P = 0 \ldots\ldots (N-1)$$

$$N_P = \left(\left(X_1 + p(S\cos\Theta)\right), \left(Y_1 + p(S\sin\Theta)\right)\right)$$

$$\phi = 90 + \Theta$$

$$NL_x = \frac{LN}{2} \cos \phi$$

$$NL_y = \frac{LN}{2} \sin \phi$$

$$N_T = ((N_{px} + NL_x), (N_{py} + NL_y))$$
$$N_B = ((N_{px} - NL_x), (N_{py} - NL_y))$$

$$p = 0..(N-1)$$

- FOR EACH ROW OF PREVIOUS TABLE
ie each value of N.

$$CP = \left(\left(N_B x + m \left(L \cos \emptyset \right) \right), \left(N_B y + m \left(l \sin \emptyset \right) \right) \right)$$

$m = 0 \ldots (M-1)$

Then use table to do look up.

B.2.4. JM'S VERBAL PROTOCOL AND DESIGN WORKINGS

00.00.00
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) OK .... You are required to design an integrated circuit that can perform the following computer vision task. Process an area of RAM memory that contains a 2-D .. TV image. The chip will be sent two X, Y coordinate pairs, and constants N, M and omega. The coordinate pairs X, Y start and X, Y end define the position of a line vector drawn over memory. The chip then has to calculate N coordinate pairs along the line vector. At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given line vector. Using stepping factor omega form M coordinate pairs. Refer to figure one .... M coordinate pairs .. At each normal coordinate pair fetch the nearest pixel from memory and summate its value according to the expressions below, generating two data items for each normal vector, g(x) and h(x). They are returned to the host ..

00.01.25
(STATING INTENTION) So I'll just read it again <Certainly yeah. You've got the gist of talking aloud anyway>

00.01.34
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) .... <Experimenter prompt> .... OK ....

00.03.17
(STATING INTENTION) Well as it's all in words at the moment I'll draw myself a little picture ....

00.03.24
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS, SKETCHING GRAPH) So we've got a picture RAM .. TV picture .. and X, Y coordinates .. and we've got to draw a line .. You're given the start position and the end position .. and this figure omega ....

00.04.15
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS, MAKING NOTES) So .. we've got start position .. X, Y start .. (unintelligible here) .. X, Y start ... X, Y end .. and we have constants .. N .. M and omega .. N is the number of coordinate pairs ... pairs .. At each coordinate pair generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .. Using stepping factor omega and M .. I'm not sure what they are .... Stepping factor omega and M .. It says it's 8 bits deep .... Generate the appropriate coordinates for a line vector at a normal to the given line vector .. Oh sorry, M coordinate pairs - that's the number of coordinate pairs for the .. for the normal ... <N and M are given on the diagram> Yeah .. Use stepping factor omega .... On the diagram you've got, uh .. N, some of the numbers there or ..

00.06.35
(QUESTIONING INVESTIGATOR, COMMENTING TO INVESTIGATOR) What's this one? <That's N and that's M, and that's M and that's N> That's N <is 8> and M

<Yeah> .. OK <You're not actually given a value for omega> ....

00.06.55
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) OK. So .. Yes. OK. So M coordinate pairs and each one is stepped by omega .. At each normal coordinate pair fetch the nearest pixel from memory and summate its value according to the expressions below .. OK .. Generate two data .. generating two data items for each normal vector, g(x) .. These are returned to the host .... You are required to design an integrated circuit ....

00.07.41
(APPLYING KNOWLEDGE OF DETAILED HARDWARE CONSTRAINTS TO ABSTRACT HARDWARE SOLUTION CONCEPT) Yes well the initial line .. you are given the start .. begin and end coordinates for the initial line, and you are also given the number of coordinate pairs - and this obviously may be a bigger number than you can .. than you've actually got definition in the RAM for ....

00.08.04
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, MAKING NOTES) So .... my overview of the chip would be .. have an area of RAM .. This RAM has got the 2-D image permanently stored in it - well it's got in there some .. in some fashion before we start processing .. Uh .... My chip will have coordinate start .... start 1 .. start 2 ... end 1 and end 2 .. coordinates of a line .. and N ... come into the chip .... (unintelligible here) coordinates for a line vector ..

00.09.24
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, GENERATING MATHEMATICAL SOLUTION CONCEPT, MAKING NOTES) You have to decide whether N is in within range or not .. In other words N might be too big for the start and end coordinates .... We can work .. So the first task .. uh .. tasks to do ... Calculate the length of the line .... of line .. (2) .. Divide length .. call that L1 .. Divide length L1 .. by N .... Check to see .. that N is greater than .. 1 pixel ... If it's .. uh .. If it's greater than 1 pixel .... everything's all right. If it's less than one pixel .. then we have to go along a different route .. - The coordinate pairs become very easy then ... So .. uhm ... modify .. If N is ... Divide length L1 by N. Sorry, this is .. uhm ... N coordinate pairs .. Test to see that N .. to see that the answer from (2) is greater than 1 pixel. If it's greater than 1 pixel .. then go ahead and do some more computation .. If it's less than 1 pixel .. then modify N. N becomes equal to .. 1 over however many pixels are within .. within the length of (unintelligible word) L1 .. Modify N, equals L1 over .. number of pixels .... (unintelligible here) ... Greater than .. If it's greater than 1 pixel we .. calculate .... each .. coordinate .... using N .. using L1 over N .. as the stepping factor ...

00.13.31
(STATING INTENTION) Just read the problem again - just in case I'm going off the wrong track ..

00.13.36
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Process an area that contains a 2-D TV image. The chip will be sent two X, Y coordinate pairs .. and those constants .. The coordinate pairs X, Y start and X, Y end define the positions of a line vector drawn over memory. The chip then has to calculate N coordinate pairs along the line vector ..

00.13.55
(EVALUATING PROGRESS) Just to see. So I've done a check ..

00.13.58
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, MAKING NOTES) Got two routes .. So this will produce, uh .. Calculate each coordinate pair using stepping factor .. Uh, this may involve .. Uh .... I can do that here .. (unintelligible word) step modify .. coordinate pairs ... calculated above ... to exact pixel coordinates .. So we may do a bit of math's here and end up with pixel number 2.3 .. which you can't have, obviously .. Uh, so this will do .. do that ..

00.15.03
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) On the block diagram .. got, uh .. another piece of decision logic here .. called LOGIC 1 .... That does all these math's, uhm .. This could be a fairly big piece of logic in terms of the chip size .. because there's going to be an Adder in there .. there's going to be .. a Comparator .. and there's going to be .. a Divider ... - which .. would be done by sub.. uh, iterations .. around an Adder probably .. or a Multiplier ... Out of here magically pops this number .. which are the coordinates .. that will have to be stored in a .. an intermediate RAM .. or worked on one at a time .. So I will at the moment store them in a RAM .... Uh, this is the .. RAM memory ... I'll call this, uh .. SCRATCH RAM 1 .. So in here are the coordinates .. the required coordinates .. How we do them I'll figure out later ...

00.17.11
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .. Using stepping factor omega form M coordinate pairs ..

00.17.24
(SELECTING SUBPROBLEM) So the next part of the processor ..

00.17.30
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, GENERATING MATHEMATICAL SOLUTION CONCEPT, MAKING NOTES) You have a starting point .. which is .. the coordinates you've just .. in turn that you've just described .. just calculated ... And this will .. This is an easier task .. You have the gradient - which - It's a normal - So I assume is 90 degrees ... Yes it must be .... (unintelligible here) .... So .. Uh. I'll just put calculate M .. Calculate .. points .. along the normal .. using .. Use pixel coordinates .. How long? .... We'll call these coordinates .. -

these will be in an array - .. pixel coordinates 1 .. and they will be in the form of RAM or an array .. Some .. Some index .. N .. a bit confusing - alpha .. Calculate points along the normal using each coordinate .. coordinate in PC1 .. of (1 .. to alpha) equaling as starting point ... point ... Direction given by .. uh .. 90 degrees to line .. L1 .. Each point ... Each successive point ... on line L2 .. Successive points along the normal .. call this .. line L2 .. Each successive point on line L2 .. given by simple ... math's .. given by simple math's using .. factor omega ..

00.21.04
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) So another input here .. omega .. to the chip .. Another massive piece of logic ... Out of here comes .. What shall I call this? .. PC1 ... (one .. to alpha) .. Out of here pixel coordinates 2 .. (1 .. to .. well .. to M) .. That's right, this is not alpha, is it, it's N .. N dashed .... (unintelligible word) length L1 .. Divide length L1 by N to see that ... L1 over N is less than 1 pixel .. Using L1 .. Stepping factor .. This is N dashed .... Not N dashed is it .. Modify N .. N dashed .. Pixel coordinates PC1 .. Is an array (1 .. to N dashed) .. Calculate coordinates along the normal line L2 using each coordinate in PC 1 (1 to N dashed) as the starting point. Direction given by 90 degrees to line L1. Each successive point on line L2 given by simple piece of logic using factor alpha .. omega ..

00.23.06
(SELECTING SUBPROBLEM, READING PROBLEM SPECIFICATION) And then, at each normal coordinate pair fetch the nearest fetch the nearest pixel from memory .. and summate its value according to the expressions below ..

00.23.17
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, QUESTIONING SELF, MAKING NOTES) So .. everything so far has been done by exact math's .. So .. we could miss out the step (4) here and do it all at the end ... because we find the nearest pixel from memory .. So .... So, prob... Give ourselves a bunch of questions .. The first one is ... Do ... Uhm .... Is it easier ... to calculate exact coordinates at stage (4) .... stage (4) .. or ... after ... uh ... uh .. after the line.. after the normal is calculated? .... Is it easier to do that at the moment? It should be easier to do it afterwards .. because math's is math's with these things. Exact numbers .. or .. fiddly numbers .... And .... That gives out 2.

00.25.18
(RE-SELECTING SUBPROBLEM) And then .... calculate g .. and h ..

00.25.30
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) From memory and summate its value according to the expressions below, generating two data items for each normal .. These are returned to the host .. 2-D .. OK.

00.25.44
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT) So that's the third bit of logic ... which out pops .. g and h .. stored in some external RAM ..

So .. the chip, I imagine, would have this ..

00.26.11
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPT, QUESTIONING SELF) That's another question .. Do we have an on ... chip RAM ... or do we read from external RAM? ..

00.26.26
(APPLYING KNOWLEDGE OF DETAILED HARDWARE CONSTRAINTS TO ABSTRACT HARDWARE SOLUTION CONCEPTS, SPECIFYING RESOURCE USAGE CONSTRAINTS) It's not really a problem here. This is a problem of specifying the chip - Whether it's practical or not, or whether people actually want .. the external RAM .. or would it be an advantage to have it on the chip .... So, step (6) .... So as an overview, I have a chip - We don't know whether to have an on chip RAM or not. To decide this you have to look where this is - as a chip - where it's going in the market place .. uh .. There's going to be a lot of other logic here. It may be relevant to think things like that at the moment because this logic may be too .. too big anyway .. and there may not be enough room for this RAM .. Uhm .. I guess if there was a RAM here .. once you've calculated the answers you can bung them off the chip and read in new values at the same time .. for the next piece of arithmetic ...

00.27.44
(SUMMARISING PROGRESS) So, the chip has 3 main pieces of logic: calculates the first line, calculates the second line, calculates g and h .. And it has all these as inputs .. g and h has sines and cosines.

00.28.02
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SPECIFYING PERFORMANCE CONSTRAINTS) Oh dear! - That means ROM .... And .. it will take some time to calculate these functions because they're summed over a whole line .. Oh dear! ... So .... I presume this is going to be done as quick as possible, because that's the way you do it in a chip and not in software ... So there may be some intermediate storage areas .. - On-chip RAM or external ROM ..

00.28.50
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPT, QUESTIONING SELF, MAKING NOTES) Third question: Do we need ... uhm .. intermediate .. RAMs .... bearing in mind .. that .... LOGIC 3 .. involves many iterations? .... This RAM would have been 512 by 512 .. and .. we're only talking about 8 bit data - which is a relief .... (unintelligible here) ....

00.30.33
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, QUESTIONING SELF) Well, right .... We have to draw .... These values g and h - It says they are returned to the host .... Are they drawn on top of the video image? .. If not .... We are not (unintelligible word) have to store the image do we .. So they must be ... drawn on top .. What are these functions anyway?

00.31.36
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS)

.. Summing, sine .. (k.i) .... I'm not really sure at the moment .. what we are going to do with this .. these results, and what they are ...

00.32.36
(STATING INTENTION) So I have to go and ask somebody ..

00.32.45
(QUESTIONING INVESTIGATOR) Do you know about the problem? <Uh, I'm not an engineer, so it's a bit .. vague to me> ....

00.33.06
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, READING PROBLEM SPECIFICATION) OK. I just assume that g and h go back to the host computer somewhere and are stored for the future of the nation ... (unintelligible here) a RAM memory that contains a 2-D .. image .. We don't need the, uh .... x .. is the current pixel .. So we do need to store that, because it's got the value of x in this last computation ...

00.33.42
(SELECTING SUBPROBLEM) OK. So .. LOGIC 1 .... We have to calculate the length of the line. That's what I said - Calculate the length of the line L1 ...

00.34.01
(WRITING MATHEMATICAL EXPRESSIONS, SKETCHING GRAPHICAL MODEL) So L1 .. is equal to .... uh .... START 1 .... START .. x1 .... x, y end .. x, y .. (unintelligible word) ... x .. start .. coordinate s .. x .. sy .. ex .. ey ....

00.35.32
(QUESTIONING SELF) So what we got to do with that? ..

00.35.34
(GENERATING MATHEMATICAL SOLUTION CONCEPT) Pythagoras ....

00.35.41
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, SPECIFYING DESIGN PROCESS CONSTRAINT) Bet there's an easier way of doing it ....

00.36.02
(GENERATING MATHEMATICAL SOLUTION CONCEPT) (unintelligible here) triangles .. (unintelligible here) given ..

00.36.11
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) No. Do Pythagoras .... So .. Uh .... We call this t1 and t2 .... t1 is equal to .. uhm .. (end x minus .. sx), and that's the (unintelligible word) of that - if the line's going the other way .... So .. and t2 is this, equal to (ey minus .. sy) ... and then .. the desired length L1 is obviously equal to the square root of (t1 squared plus t2 squared) .... So .... And then each point ... divide by, that by N ....

00.37.54
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS) That's easy to do .. Do that in 1 cycle of the chip. We can do that in 1 cycle .. We can square them in .. well .. 1 cycle, if the chip's slow .... Square roots .. I suppose that's an iterative process on a chip. I've not really come across this yet ... But that's easy, that's easy .. The squaring is easy .. The square root is not so easy .. And also .. uhm .. we have to have a factor here .. Divide it by N .. L1 by N - stepping factor .. Better call that something I suppose - the problem doesn't .... Stepping factor equals .. It's called Line 1 - So .. Stepping Factor 1 .... Stepping Factor 1 is equal to L1 over N. That's going to be difficult to do .. That's difficult and easy ....

00.39.27
(SELECTING PROBLEM) So, how do we do that? ..

00.39.30
(STATING INTENTION TO DEFER WORK) Worry about it in a minute ..

00.39.33
(SELECTING SUBPROBLEM) LOGIC 2 ...

00.39.37
(RE-SELECTING SUBPROBLEM) Oh, sorry, that's .. not quite it. Got a stepping factor. You may have to work out the coordinates ..

00.39.50
(GENERATING MATHEMATICAL SOLUTION CONCEPTS) So .... Uh .. I should have worked out the angle I suppose .... The gradient .. If I had the equation of that line .. The equation of a straight line is $y = mx + c$ .... Uhm ....

00.40.57
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) To go along this route now .. you would know .. a stepping factor .. you would know .. the length, but .. you don't need that now - you need that to calculate stepping factor .. And you have a starting point .. starting point .. and the finishing point is not important now, because it's all taken care of in the stepping factor .. Uhm .. You have a point .. You don't know which way you're going unless you know the end point. So .. to pursue this .. you're only going to reinvent the wheel, and end up doing this all to math's again ...So, you need to know which direction it's going ... I suppose that gives you the normal - back to my earlier point - the normal is 90 degree, that's 90 degrees in some direction ... Uhm .... Uh ... I'm not sure whether it is or it isn't, but it doesn't make any difference if it's changed ... So, if we went (unintelligible here) of the equation ..

00.42.34
(QUESTIONING SELF) Would that make it any easier in the long run? ..

00.42.38
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF HARDWARE CONSTRAINTS TO MATHEMATICAL SOLUTION CONCEPTS) We would then

have .. a starting point s (x, y) .. stepping factor ... and .. which way we were going .... Don't want to get involved in gradients really ... because that involves .. working out .... Well. OK. We've got a .. We've got a ROM on the chip anyway .. So .. - to calculate the third step .. So we may as well use that ROM .... So ... back to here - we don't do this any more. Calculate length of line L1 .. Divide it by N - that gives .. Stepping Factor .. 1 .. Uh, modify coordinate pairs - so we don't know whether we're doing step (4) ... here .. (3b) - calculate gradient .... And once you've got the gradient .... Well. I'd have to think about that .. We've got all the knowledge there. We've got your ROM .. for when you have your gradient, to calculate a new point, if you needed to with sines and cosines ....

00.44.58
(STATING INTENTION TO DEFER WORK) So I'll think about that in a minute ....

00.45.45
(SELECTING SUBPROBLEM) Second piece of logic ....

00.45.11
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Does what? That calculates the line .. on the normal .... So it's the same problem really. You've got a gradient .... Same problem as LOGIC 1 - just different inputs ....

00.45.47
(STATING INTENTION TO DEFER WORK) Leave that for now ....

00.45.54
(SELECTING SUBPROBLEM) And the third logic step.. piece of logic is to calculate .. g(x) ...

00.46.00
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, READING PROBLEM SPECIFICATION, WRITING MATHEMATICAL EXPRESSIONS) .. g(x) ... is equal to .. g(x) .... is equal to x-one .. sine ... (360 over M ... (360 over M times .. 1) .. I'll write it as a series so I can see what's happening .. x-two .. is sine of (360 over M times 2) .. Oops ... Right .. plus so on up to .. M points .. x-M ... sine (360 over M .. times M) .. OK.

00.47.14
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So these .. uh, sequential positions in our ROM ... So this stage - in terms of silicon - it's just accessing the ROM .... multiplying the value, reading from the Video RAM .... and storing it in one temporary storage register .. which is an Accumulator, and it's accumulated with the next piece of data which .. is just reading the value of .. the next value from the ROM ....

00.48.04
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So this is actually easy .. The same with, uh .. h .. Just the same things with cosines .... So that's the easiest step ....

00.48.39
(SELECTING SUBPROBLEM) So how do we calculate ... these things .... So we've got a line ..

00.48.55
(STATING INTENTION) Let's do it with a real .... Let's do it with a real, uh .... line ....

00.49.15
(COMMENTING TO INVESTIGATOR) I always find it easier to draw a real example .. To write the theory after that ..

00.49.23
(SKETCHING GRAPHICAL MODEL, GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) 2, 3, 4, 5 .. Make it easy .. and have point 2,2 and 4,4 .... So .. x1 would equals 2, y1 equals 2 ... x2 .. 4 .. y2 equals 4 .. We have a stepping factor. This is line 1 - Got the notation I had before. Stepping Factor 1 .. and we calculate it to be .. Uhm .... Well .. I calculate (unintelligible here).. or root 2 .. It makes it easier, that means, if the next point is 3,3 .. But we don't know that yet .... Uhm .... Uh .... Perhaps you don't take the modulus there; all this gradient rubbish will take care of itself .... Yes, I think so .... We couldn't consider it as a 1-D problem could we? ... We can't just consider x by itself? .... Uh .. x1 equals 2, x2 equals 4 .. SF1 is equal to 1.414 .. I think it will work in this case because it's symmetrical .. Uh .. Therefore, first point ... equals 2, .. second point equals .. 2 plus 1.414 .. 3.414, ... third point ... (unintelligible here) .. uh .. gone over the 4 .. Well it should be .. 3.414 plus 1.414 .. equals 4.8 .. So .. at the y .. the same thing again .. So the first point .... is 2 and the second point is 3.414 ...

00.52.56
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) You can't do it this way! .. I had to make sure ....

00.53.26
(EXPLAINING TO INVESTIGATOR) No. I'm thinking of it in terms of Adders and .. things. You've got to think of it in terms of equations ....

00.53.45
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) (unintelligible word) process this logic (unintelligible word) an equation ... You do that, and you do that, do that. You've got to do this to get the scaling factor ... Uhm ..

00.54.00
(STATING INTENTION) Got to work out the equation of the line ...

00.54.03
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) Which - I know there's a formula for that because I remember doing it in school .. When you have 2 points .... I'm not going to bother working it out here, but it's, uh .. (y2 minus y1) is equal to ... I don't know - (x2 minus x1)

.. Uh .. I don't know at the moment .. But somehow it gives you a formula, just very simply .. It has to, you've got 2 points .. So you've ended up with a formula of y = mx + c .... You want the y and x .... So .. And to calculate the new point - we get away from chips and go on to math's - it's .. the new .. y-new is equal to mx-new plus c .. And we also know that .. the square root of .. (y-new minus y-previous point .. old) .. squared .. plus .. (x-new minus x-old) .. squared .. - the square root of that .. is equal to a scaling factor ...

00.56.04
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF HARDWARE CONSTRAINTS TO MATHEMATICAL SOLUTION CONCEPT) So we know it fits that equation .. and we know .. that Pythagoras is true .... Oh .. uh .. yn minus yo .. Chips can't really do square roots very well ...

00.56.33
(GENERATING MATHEMATICAL SOLUTION CONCEPT) But we can square ... uh .... Can expand those out.

00.56.43
(QUESTIONING SELF) Is that going to get them anywhere? ....

00.56.50
(STATING INTENTION) Uh ... Well let's have a look ..

00.56.55
(EVALUATING SOLUTION CONCEPT) yn squared .. plus yo squared .. minus 2ynyo .. Yes, it's the same for xn .. equals SF1 squared ...

00.57.19
(QUESTIONING SELF) Uh, have I done that right? ..

00.57.22
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) y squared .. plus y squared .. yn .. yo .. uuuhh ... (unintelligible here) .. Crikey .. yo .. yn minus yo .. yn squared plus yo squared .. minus .. Oh well, that's right .. ynyo .. minus ynyo .. So it's right ..

00.58.04
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) Uhm .... (Unintelligible here) of x .. That's xn squared plus .. xo squared minus .. 2xnxo ... Still the unknowns in here are yn .. and xn .... And we have the formula up here .. where the unknowns are yn and xn .. Two simultaneous equations .. But one's got squares in it .. Could you believe it! .... yn squared .. minus 2ynyo .. - That's a constant - .. yo squared .. plus xn squared .. 2xnxo .. constants .. yo squared plus xo squared, equals SF1 squared ... yn squared .... is equal to .. uhm .... C1 .. Constant 1 ... Uh, better not use C because that's .. crossing point to the x.. y axis .. Uh, K constant .... yn squared, blah, blah, blah ... Got a yn up there - can substitute that into there ...

01.00.19
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) It's all going to come out quite .... (unintelligible here) .. Uhm .... I think it boils down to calculating m as far as the chip is concerned. But yn will go in there .. and you get a quadratic .. If you substitute yn into this equation from here .. you will end up with an equation with x squareds in ... and xs in, which is going to boil down to a quadratic .. which is .. it's got square roots in ...

01.01.05
(QUESTIONING SELF) So .. what's that formula?

01.01.08
(GENERATING MATHEMATICAL SOLUTION CONCEPT) Of a quadratic is .. equals .. b squared .. plus or minus the square root of 2ac .. over 2a .. 4ac. That's not right! .... Yes, of course that's right! .. So we're going to end up, if we do that .... Put that into there .. We end up with a quadratic - which the solution is that.

01.02.07
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) In terms of the chip, this is easy to do, these are easy to do. We end up with another divide .... So, as far as the chip design is concerned .. everything points to .. lots of divisions everywhere.

01.02.27
(STATING INTENTION TO DEFER WORK, MAKING NOTES) So we have to work out .. a nice way of doing that. So that's a problem for the future. Big problem! Uh .... Efficient method ... of dividing .... Uh, C------ will have some routines for that .. I don't intend repeating all that work ....

01.03.02
(GENERATING MATHEMATICAL SOLUTION CONCEPT) So .... That is, the same problem .. can be applied to the second .. uh, logic block .... I'm sure that's right ..

01.03.22
(STATING INTENTION) I'll just write it out again in case ..

01.03.27
(STATING INTENTION, COMMENTING TO INVESTIGATOR) No I won't! .. <Are you doing all right?> I think so ... Uhm ....

01.03.46
(SUMMARISING PROGRESS, EVALUATING MATHEMATICAL SOLUTION CONCEPTS, MAKING NOTES) That's what we do. We calculate the line - the length .. and divide the length by N to get a scaling factor .. We do a check - we don't have to do that if we're not doing stage (4) .. We do all that in the last part, when you find the nearest pixel; that will save logic ... Uhm .. You calculate the gradient .. With that you can work out these equations .. Calculate points along the.. No .. Calculate each coordinate point ... I've done that in the same stage as the check, so that's not really .. That should be (3a) - the check - if I'm doing it .. (3b) should be calculate the coordinate points, and (3c) .. calculate

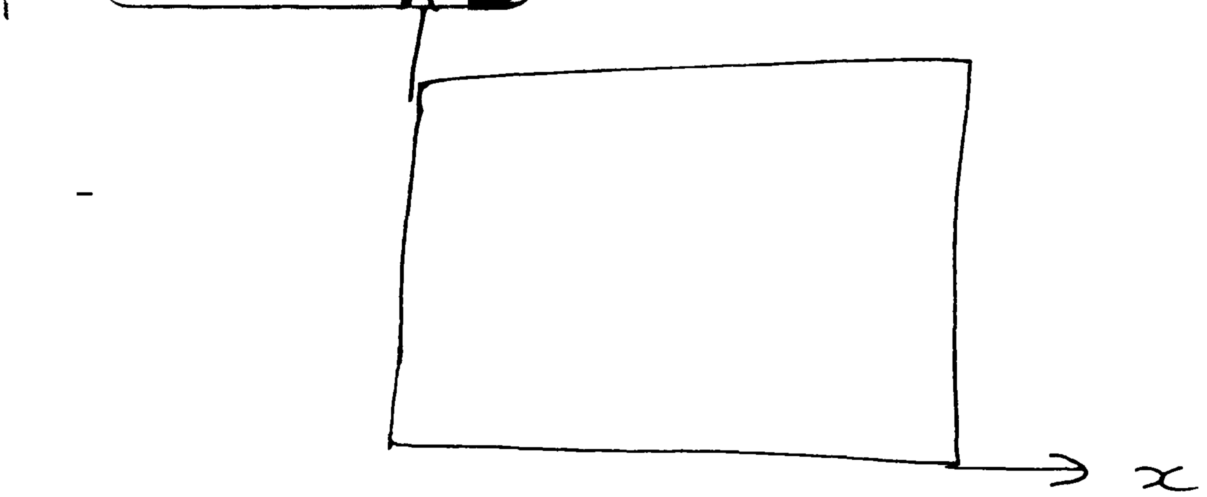
the gradient .... Uhm, calculating each coordinate point. That involves .. solving this .. equation, when I substitute that into there .. and use the quadratic formula to .. to solve it ... which involves square roots - that's another thing ask C------. I'm sure it's the same problem as dividing .. Square roots .... Uh, yes that's the si.. If.. if that works and there's not a simpler way, I'd have to look into doing it a simpler way .. But you obviously need to know the gradient. So we'd have to calculate that out - to know which way we're going. Perhaps there's an easier way to do it when you calculate the line .. the length of the line .. Uhm .. the fact that .. Uhm .. Uhm. If you don't take modulus here ... Depends on this, this, the .. whether the answer is positive or negative .. The gradient's all wrapped up in that, so there might be an easier way to do that. I'll have to look into that .. Uh. And if that works .. the same thing can be applied to LOGIC 2. In fact on the chip that can be the same piece of logic .. probably ... And LOGIC 3 - that's .. that's dead easy! ... Spit the answer out.

01.06.28
(QUESTIONING SELF, STATING INTENTION) So what does the chip look like? ...

01.06.32
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Uh. May or may not have your RAM ... Video .. RAM .. May or may not be on the chip .. Uhm .... Should have been a (unintelligible word) .... Calculate ... Scaling Factor 1 ... and calculate gradient m. Ooh! That's a clash with the, uh, number of points with a normal .... m gradient ... and that, and we've got a central processor here which can do both .. Working the points on the n... on Line 1 and Line 2 .. normal. So .. uhm .... This is going to involve adders and dividers and things, so I'm not going to repeat the logic twice .. Calculate SF1. So that's .. an input into here .. Need scaling factor .. N gradient .. Need coordinates .. coordinates .. 1, coordinates 2 .. Uhm .. Maybe, after you've calculated each point on .. as you calculate a point on Line 1, you calculate a point on Line 2 - all the points ... and then do it like that .. So say you have an intermediate storage ... So I think I've had that - I've got that as a question: Easier to calculate ... OK. Uhm .. On chip RAM .. OK: Do we need intermediate RAMs, bearing in mind that LOGIC 3 involves many iterations? .... Uh .. Question (5) ... Do we calculate .. uh, the.. Line 2 ... after .. every point ... on Line 1 .. After every point on Line 1, or .... or whole of Line 1 first? .... Or whole of Line 1 first? .. Uh, PROCESSOR, uhm ... uh, LINE PROCESSOR .. It's as good a word as any! .. That will .. The ROM .. is used to calculate SF1 .. the gradient, I mean .. And .. call this a gh PROCESSOR .... After each .. result squirts out .... Uh, at each point .. you need to store the points .. So you need to have an intermediate RAM definitely .. to store the points. Either you store the points of Line 1 - you might as well, that's easier to think about .. LINE PROCESSOR .. squirts out Line 1 ... So squirts out coordinates of Line 2 .. The RAM goes into the gh PROCESSOR .. (unintelligible word) selecting values from the ROM. So you need .. an ADDRESS GENERATOR .. for the ROM, which is going to have to ... It depends on the length of the line and things - you're going to be

reading different things from the ROM - maybe .. I have to look into that ... Uhm .. This involves .. This is where the RAM (VIDEO) comes in .... and this all pops out of the bottom ... This is obviously the top. These in the top are the .. two coordinates and N .. and the omega and M .. So .... Uh .. Start coordinate .. End coordinate .. Uh .. Omega .. N and M .. And out go g .. and h ... Uh. That saves a lot of logic on the chip .. This may be awkward to do for different line lengths .. Uh .. Oops .. Uh ....

01.12.38
(COMMENTING TO INVESTIGATOR) So that's it for now. I'll have to go and have a cup of tea and think about it now.



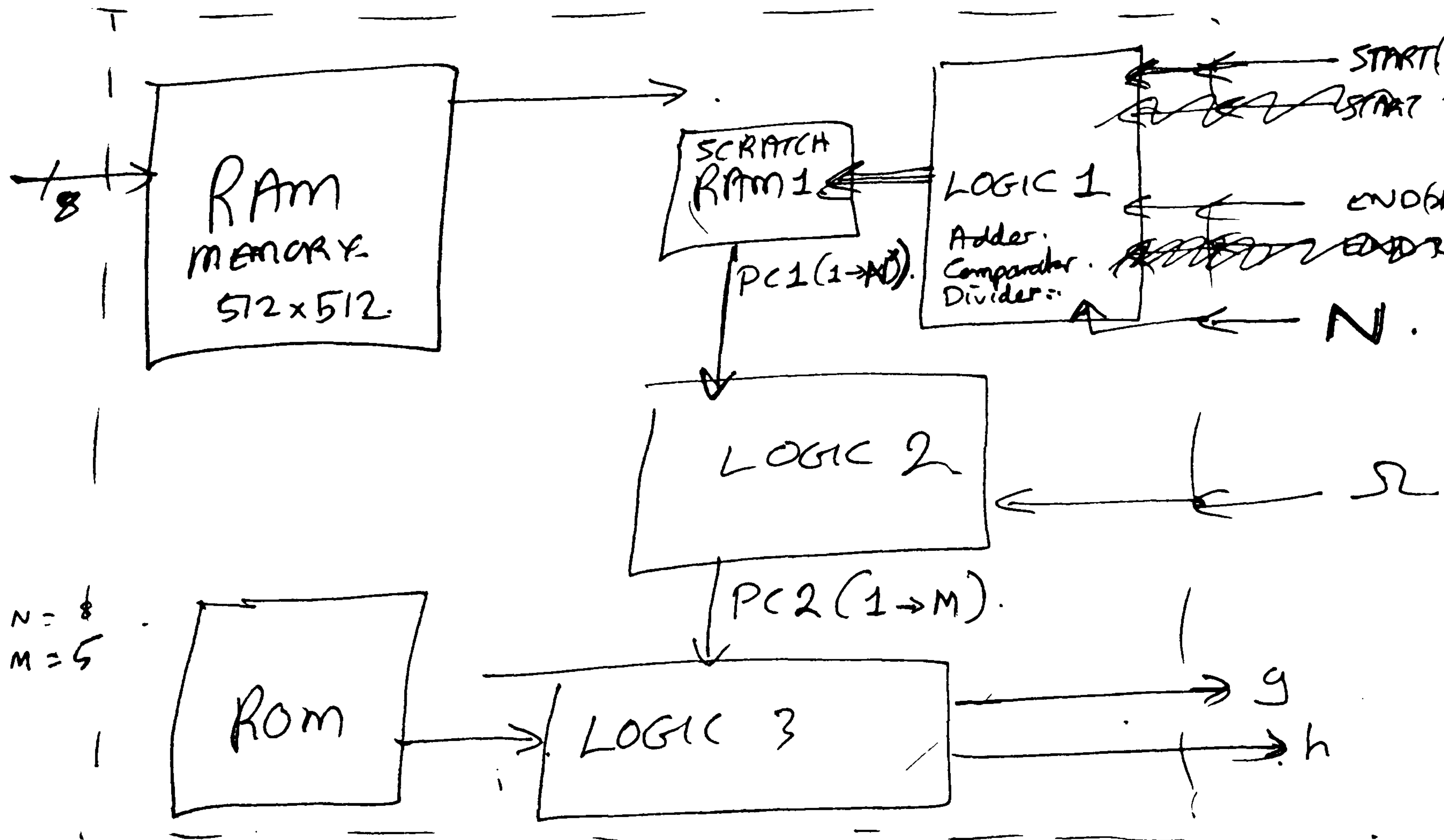
x y start.

x y end.

N → № coord pairs.

M → " " " for Normal.

Ω.



~~4.~~ ⑤ Do we calc ~~RM~~ L2 after every point in L1 or whole of L1 first

① . ~~Dq~~ Easier to calc exact coords at stage ④ or after Normal is calculated .. ?

② On chip RAM or read from Ext. Ram.

③ Do we need intermediate RAM's bearing in mind that ~~sto~~ LOGIC 3 involves many iterations.

④ Efficient method of dividing (see C[illegible]). – SQUARE ROOTS ?

TASKS TO DO.

2

(1). Calculate length of line = L1.

(2). Divide length (L1) by N ⇒ SF1.

(3a) Check to see that (2) > 1 pixel.

> 1 pixel → (3b)

< 1 pixel → Modify N = $\left(\frac{L1}{N^\circ \text{ pixels}}\right)$ ⇓ = N′.

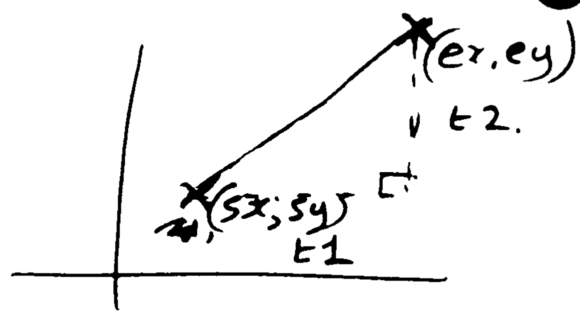
(3b) Calculate Each coord using $\left(\frac{L1}{N}\right)$ as stepping factor = SF1.

(3c) ⇒ Calculate gradient

(4). Modify Coord pairs calculated above to exact pixel coordinates ⇒ PC1 (1 → N′)

(5). Calculate points along the Normal (line L2) using each coord in PC1 (1 → N′) as starting point.
Direction given by 90° to line L1.
Each successive point on line L2 given by simple Maths using factor Ω :

(6). Calculate g(x) & h(x).



$t1 = |ex - sx|$ ✓

$t2 = |ey - sy|$ ✓

$L1 = \sqrt{t1^2 + t2^2}$

$SF1 = \frac{L1}{N}$ ×

Eqn of line.
$y = mx + c$

$(y_2 - y_1) = (x_2 - x_1)$

$y = mx + c$

$y_n = mx_n + c$

$\sqrt{(y_n - y_0)^2 + (x_n - x_0)^2} = SF1$

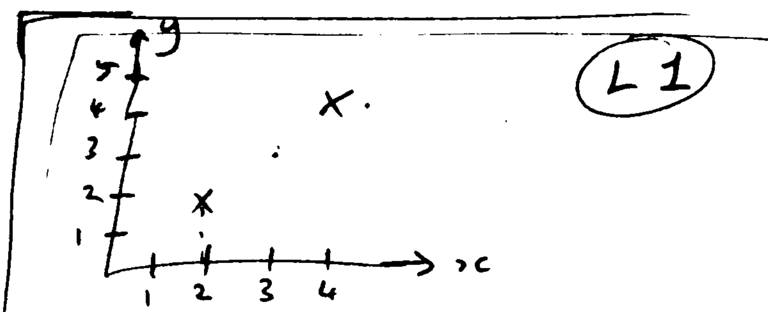
$(y_n - y_0)^2 + (x_n - x_0)^2 = SF1^2$

$(y_n^2 + y_0^2 - 2y_n y_0) + (x_n^2 + x_0^2 - 2x_n x_0) = SF1^2$

$y_n^2 - 2y_n y_0 + x_n^2 - 2x_n x_0 + y_0^2 + x_0^2 = SF1^2$

$y_n^2 - 2y_n y_0 + x_n^2 - 2x_n x_0 = K1$

$x = \frac{b^2 \pm \sqrt{2ac}}{2a}$



$x_1 = 2$ $x_2 = 4$ $SF1 = \sqrt{2}$
$y_1 = 2$ $y_2 = 4$ $= 1.414$

$x_1 = 2$ $x_2 = 4$. $SF1 = 1.414$

∴ 1st point = 2
2nd pnt = 2 + 1.414 = 3.414
3rd point = 3.414 + 1.414 = 4.8

$y_1 = 2$ $y_2 = 4$.
1st 2
2nd 3.414
3rd 4.8

$(y_n - y_0)(y_n - y_0)$

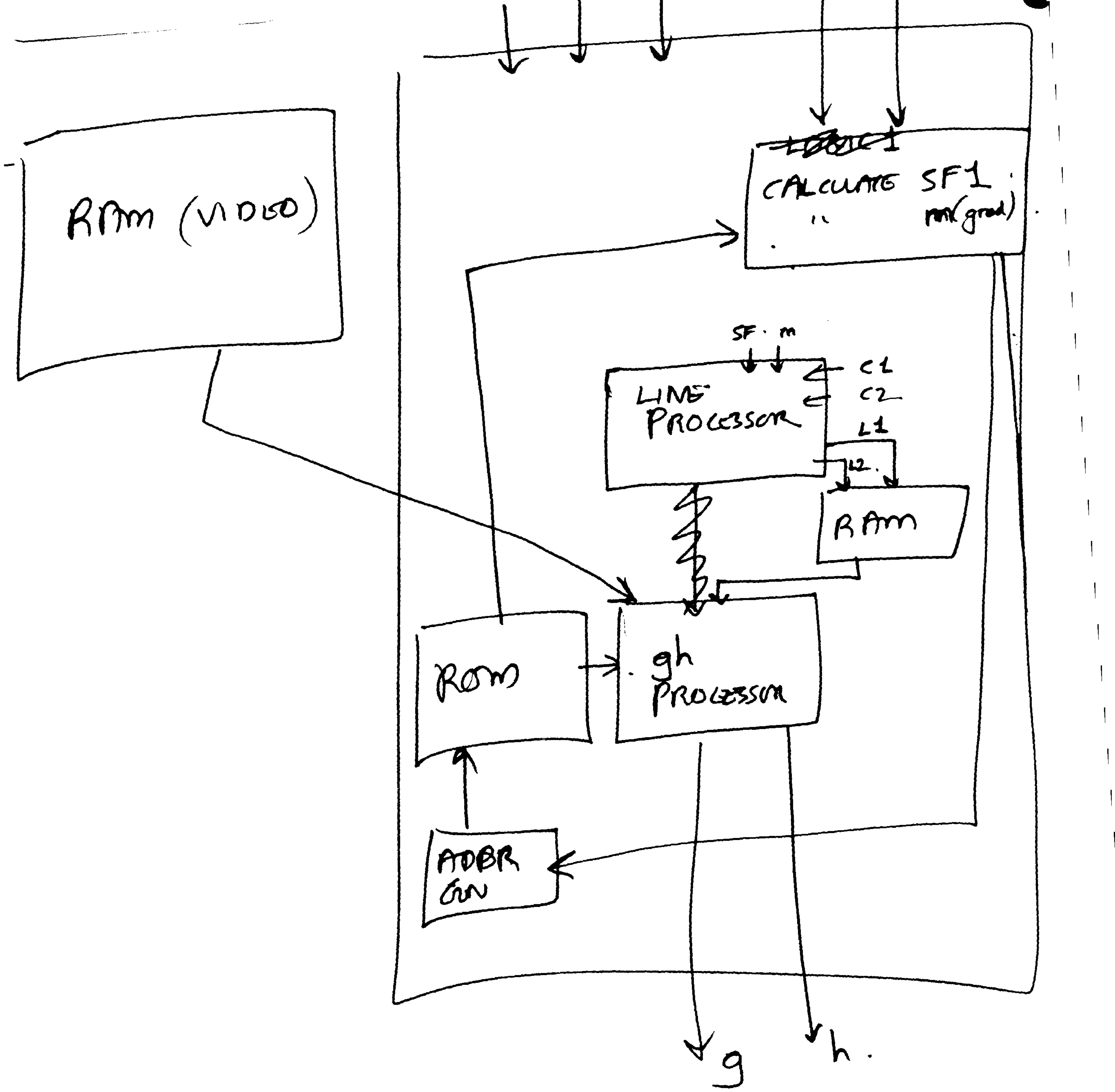
$y_n^2 + y_0^2 - y_n y_0 - y_0 y_n$

LOGIC 2

$$g(x) = x_1 \cdot \sin\left(\frac{360}{M} \cdot 1\right) + \left(x_2 \cdot \left(\sin \frac{360}{m} \cdot 2\right)\right) + \dots$$

$$+ \; x_m \cdot \sin \frac{360}{m} \cdot m$$

$$h(x) = \dots \cos \quad \dots \cos \quad \dots$$


RAM (VIDEO)
CALCULATE SF1
m(grad)
SF
m
LINE PROCESSOR
C1
C2
L1
L2
RAM
ROM
gh PROCESSOR
ADDR GEN
g
h

B.2.5. JF'S VERBAL PROTOCOL AND DESIGN WORKINGS

00.00.00
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) .... OK. Process an area of RAM memory that contains a 2-D TV image. The chip will be sent .. two X, Y coordinate pairs .. and constants N, M and alpha .. The .. coordinate X, Y .. pairs X, Y start and X, Y end define the position of a line vector drawn over the memory. The chip has to calculate ..

00.00.37
(COMMENTING TO INVESTIGATOR) It sounds like P----'s chip to me! .. <It is>

00.00.41
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) N pairs. N coordinate pairs along the line vector .. Right ....

00.01.16
(STATING INTENTION) I'll go through that again ..

00.01.18
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) Process an area of RAM .. <Yeah. If you dry up when you're talking I'll probably just prompt you> Yeah. OK. I'll <'cos I'm really keen on getting the verbalisation>

00.01.24
(QUESTIONING INVESTIGATOR) Where is it? Anywhere around here? <Yeah. Can you use that pen because it's thick and black, and just work in this area. OK> .. Right. OK ..

00.01.31
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS, SKETCHING GRAPHICAL MODEL) Process an area RAM memory that contains a 2-D TV image. The chip will be sent two X, Y coordinate pairs .... Coordinate pairs .. of a line vector drawn over the memory. The chip has to calculate ... Of a line vector ..

00.02.10
(QUESTIONING SELF, READING PROBLEM SPECIFICATION) What the hell is a line vector?! ....

00.02.26
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, SKETCHING GRAPHICAL MODEL) N coordinate pairs along each line vector ... Ah, I see! Total miscomprehension! .... At each coordinate pair so derived .... At each coordinate pair so derived, generate the appropriate coordinates for a line .... <Experimenter prompt> .. OK .... Well I've got to now ..

00.03.36
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) OK. We're going to trace along a line vector - whatever such a thing is - but it's between two points -

arbitrary points X and Y - which I'll assume are defined as complete pixels .. And we're going to trace along between those two points, a number .. of coordinate pairs ..

00.03.55
(QUESTIONING SELF, UNDERSTANDING FUNCTIONAL REQUIREMENTS) We've got, the first problem is: Does N .. bear any relationship to a practical number of coordinate pairs that there could be between such points? .. How do you round it? .. All kinds of evil questions like: How many times will you end up on one coordinate pair, et cetera, et cetera? ..

00.04.12
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Coordinate pair so derived, generate the appropriate coordinates for a line vector drawn at a normal to the given vector. Using stepping factor alpha and M .. Refer to figure 1 below. Right <That's good. That's the idea> At each coordinate pair so derived - I've just done that bit .. At each normal coordinate pair fetch the nearest .. fetch the nearest pixel from the memory and summate it's value ... according to the expressions below, generating two data items for each normal vector .. these are returned to the host .... At each normal coordinate pair fetch the nearest pixel from the memory and summate it's value according to the expressions below - g(x) equals ... Ye gods! ...

00.05.16
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS, SKETCHING GRAPHICAL MODEL) So .. I'm stepping my way along this ... from 1 .. to N, picking off points .. and then .. at coordinate pair so derived, generate the appropriate coordinates for a line vector at a normal to the given vector, using stepping factors alpha and M coordinate pairs, referring to figure 1 below. M is the total distance ... total number of pairs .... At each normal coordinate pair fetch the nearest pixel from the memory and summate it's value according to the expressions given below .... At each normal coordinate pair fetch the nearest pixel from the memory and summate it's value according to the expressions below .. Ah right! Generating the two data items for each normal vector, g(x) .. These are returned to the host ..

00.06.40
(SELECTING SUBPROBLEM) Right. So we run .. We've got to figure out what delta is - see whatever that thing is .... Ah. OK ....

00.07.18
(STATING INTENTION) OK. I suppose it's time for a few rapid assumptions ....

00.07.24
(COMMENTING TO INVESTIGATOR) I'll assume that .... You'll have to take account of the fact that I can't spell here, by the way <Oh, that's fine> Any hints that ....

00.07.45
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) I would assume that we start from a position and step across it .. and then pick points along the way

to step along .... So the first thing we need is ... The first thing we're going to need - assume ....

00.08.29
(SPECIFYING PERFORMANCE CONSTRAINT) So we're going to first of all figure how accurate we have to make the coordinate system between here and here in order to do something meaningful .. in terms of finding pixels ...

00.08.39
(SPECIFYING DESIGN PROCESS CONSTRAINTS) Goodness only knows how you would want to work that out! .... And goodness only knows how you would figure it out in advance .. So assuming that I haven't got time to figure out that.

00.08.53
(MAKING NOTES, COMMENTING TO INVESTIGATOR) .... <Experimenter prompt> Yeah, well I'm writing it down! <Ah> .. Well I would normally write things down. So you're going to .. <Uhm, yeah, well work as naturally as..> Yeah that's right. So I'm mumbling away and writing things down when come to a conclusion.

00.09.19
(SPECIFYING PERFORMANCE CONSTRAINTS) Right, I'm assuming that you need an extra 8 bits of accuracy to figure out where you would be in the picture .. in order to find out where your coordinate system was going to be, and to know where to start and where to finish - on top of the usual 512 which is - goodness only knows how many bits! - another 8 bits - to get across the thing .. 512 is .. Right, so you've got a total 16 bit system for the addressing and the - probably another 16 bit system for doing this - so assume you can do it with 16 bits - hence .. total ..

00.09.58
(COMMENTING TO INVESTIGATOR) I would really like to go back and simulate that and see whether it comes out accurate. Or figure out some way of doing it ... That would be something I'd want to think on overnight .. So we ignore that problem .. and go into the architecture required regardless of the number of bits ....

00.10.20
(SELECTING SUBPROBLEM) First of all I need to calculate some kind of system to calculate coordinates ..

00.10.26
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) First thing is to figure out a starting point .. So .. (1) .. calculate .. mid point ... (2) .... calculate .... starting ... mid .. point .... (unintelligible here) starting point ... starting .. point .... step through the normal vector .. performing calculation ....

00.11.55
(COMMENTING TO INVESTIGATOR) Why don't you just draw a line on the table where I've got to stick? <No that's fine> As long as I'm in here somewhere I'm OK am I? <Yeah there's quite a good field> Right, OK ..

00.12.04
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) At each normal coordinate pair fetch the pixel nearest from memory .. generating two data items for each normal vector .... <You seem to be getting into the verbalising now> Well goodness knows what I'm verbalising, but yes. OK .. g(X) equals sine of k.

00.12.25
(QUESTIONING SELF) What's k? ...

00.12.30
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Each normal pair, coordinate .. according to the expressions below generating two data items for each normal vector, g(X), h(X) returning these to the host - Whatever the host is .... Mmh huh .. Right. 0 to M. 0 to M. xi is ... is the current pixel .. Cos of (k.i) .... What an odd thing to calculate .... k.i. Well k is that and i is that .. Right .. OK ..

00.13.56
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT) We're going to need a Sine/Cos Generator quite a lot aren't we ....

00.14.10
(QUESTIONING SELF) How would I do it? ..

00.14.13
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT) I'm going to need some kind of engine that calculates displacements, and sines and cos's to get the coordinate system to work in the first place .. So .... And I'm going to need some kind of architecture ...

00.14.32
(QUESTIONING SELF) I have no idea how fast this thing has to be .. (unintelligible here) perform the following computer vision task ... How fast would you want a computer vision task to go to? .. How fast? .... How fast shall we make it go? ...

00.14.55
(SPECIFYING PERFORMANCE CONSTRAINTS, EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPT, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPT) Designing a chip you've got to beat the equivalent performance .... beat a microprocessor .. Eh, it's got to come somewhere near what you would do if you were designing a hardware implementation .. Beating a micro' is probably not going to be too much of problem because sine and cos is a devil to produce ... So you could do that pretty rapidly in hardware .. So .. speed is going to be miles faster than a microprocessor, come what may ..

00.15.30
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So I could either design it as a data path .. with a bit of control, or I could design it with a more complex data path and much less control - Depending on what you felt like ..

00.15.44
(SPECIFYING PERFORMANCE CONSTRAINTS, EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS) Let's go for a practical chip .... it will always be faster ... than .. microprocessor .. as .. as sine .. and cos .. difficult ... to process .. So .... make it quick ....

00.16.28
(QUESTIONING SELF) How will I do it? ..

00.16.31
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM, MAKING NOTES) Divide the problem down into a number of sections: (1) .... The thing that calculates where I want to be - How much the displacement is going to be in X and Y. So I want a .... engine to calculate .. X and Y displacements .... delta Y .. displacements .. (unintelligible here) .... along .. the what's it axis .... So out of this I get X and Y .. Then I need .... if we can take an X and Y, I need to calculate .... find .. X starting for the normal, and Y starting for the normal .. position ... which is going to be fairly simple to calculate.

00.17.57
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSION) That is going to be .. I've ended up there .. I can calculate the distance .. off in terms of .. (M funny squiggle over 2) gives me that point .. And the angle's going to be ... That angle's going to be equal to that angle .. So I should be able to ....

00.18.37
(STATING INTENTION) A bigger sheet of paper is required at this stage ....

00.18.56
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL) We know that is .. XN ... We know that distance there .. d .. So I should be able to calculate that. We know that angle .. Can know that angle there .. Know that in terms of absolute position .. We need to know .... Aha!

00.19.31
(QUESTIONING SELF, EVALUATING MATHEMATICAL SOLUTION CONCEPT) Do I need to know?.. Do I need to know the sine and cos? .. No.

00.19.37
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) I need to know the ratio between that one and that one. Hmmn, interesting! .... So if you were to calculate the ratio between those two numbers - which saves me calculating the sine and cos anyway .. then .. (unintelligible here) liable to drift off over a period of time. So I could calculate that every time .. So .. that point there is equal to .... Well that position there is equal to .... That position there is equal to .... XN .. minus .... (d over Z) ..

Well I can calculate Z in advance quite easily .... (1 - d over Z) .. (unintelligible here) YN is going to be a similar thing .. Can't be! Can't both be the. Ah!... x equals .. X of N .. minus Y of N .. d over Z, say .. and y equals X .. YN .... I can get the starting point without using any sines and cos's .. Interesting! ...

00.21.51
(QUESTIONING SELF) Can I step through it without using sine and cos's?

00.21.56
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) The answer to that's .. Yes .. should be fairly simple. Mmn. Interesting! ... So providing I know the ratio of the starting point .. then .. I think .. the ratio of the starting point .. Working out the sine of that and the sine of that is a bit of a waste of time .. Sine of that is one over the other .. one over the other the other way up .. Mmn.

00.22.30
(QUESTIONING SELF, STATING INTENTION) Can I prove that to myself? ..

00.22.33
(PROVING MATHEMATICAL SOLUTION CONCEPT, WRITING MATHEMATICAL EXPRESSIONS) Sine equals opposite over .. hypotenuse .. Cos equals adjacent over hypotenuse .. Tan equals opposite over adjacent .. So .... I can .. count Z as a function of ... Z equals opposite over hypotenuse, equals YN .. Z equals that .. and I know that .. Let's try and work out x (unintelligible here) that distance there is equal to .. a .. a is equal to .. opposite over hypotenuse .. equal to sine ..

00.23.47
(QUESTIONING INVESTIGATOR) Is it working? .. <Oh Yes!> .. It's working - Oh I'm (unintelligible word) for life here <I've got to turn it over at some point> Oh I see ..

00.23.54
(PROVING MATHEMATICAL SOLUTION CONCEPT) Right, it's got to be a sine. Opposite over hyp'.. adjacent .. Opposite over adjacent if I'm subtracting that .. from this .. because of X of N ..

00.24.08
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) Why am I somehow convinced .. that is the case? ... I'm not convinced about that ...

00.24.25
(EXPLAINING TO INVESTIGATOR) I'm spending most of my time here trying to figure out whether I need to generate sine/cos or whether I can fiddle my way around it ....

00.24.34
(STATING INTENTION) Let's have another go - bigger piece of paper ....

00.25.02
(PROVING MATHEMATICAL SOLUTION CONCEPT, APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL

MODEL, WRITING MATHEMATICAL EXPRESSIONS) a .. b .. I know d .. I know - can know z. But I don't - Let's ignore Z for now .. I want to calculate that position there .. I know those two are equal. I know that if I need to know Z. That's (unintelligible word) ... Z is easily calculable ... Just about managed that one! .... Dead easy to figure that one out - go into a Multiplier and a Square Rooter (unintelligible here) .... Couldn't have got away with that too often. So .. once I've taken in that number, I've got it. Now .... I want e .... OK. I want e given d .. d - that's the general case, 'cos once I've got d .. d's going to step throughout and it's going to pum, pum, pum, pum - calculating my positions .. So ... I need a Sine/Cos Generator eventually anyway - So I'm going to have it some time .. Hmmn ..

00.26.24
(QUESTIONING SELF) Ah, do I?

00.26.38
(APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS) Yes I do .. 'cos I've got this odd formula ...

00.26.45
(QUESTIONING SELF) Is there any point in ignoring that? .. Is there any point in ignoring sine and cos calculations 'cos I'm doing them anyway? ..

00.26.57
(APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS) Yes, got to be! I can do that independently in a different part of the chip. OK. Still a good idea to do it independently this time 'cos there is .. 'cos it means I don't need two of them ..

00.27.08
(PROVING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) So .... i, j .. Let's try and work out what j .. j equals .... sine .... theta, equals opposite over (unintelligible word), i over d .. also equals .. b over Z .... Therefore .. j equals .. b times d over Z ... Is that coming out the same as it did before? ... Therefore .. the position here which I shall call m,n .. m equals .... b minus b times d over Z .. What's d? - d's that distance.

00.28.44
(QUESTIONING SELF) So is that the same as last time?

00.28.46
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) b equals .. XN .. Well given a chance and I'll (unintelligible here) ... b equals .. (XN - YN) ... Managed to exclude YN this time .. Jolly good! .. Yes, totally different answer!

00.29.12
(STATING INTENTION) Right .... OK. Let's get down to the real question then ..

00.29.19
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL, WRITING MATHEMATICAL EXPRESSIONS) So now I've got ... a coordinate system .. distance d .. Z .. a .. b .. Now I want to find mn .. m equals ... b .. (1 minus d over Z) ... and n equals .. a ... Right I've got some starting points, and d is going to step through and going to give me lots of answers for that .. So if I calculate that every time I'll lose any inaccuracies .. OK. Come back to where I first started ..

00.30.17
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS) Finding that position is now going to be fairly simple .. I just use those formulas to get it. That's going to get me a starting position, and those .. So .. all I need to input into that is - .. calculate delta X, Y positions along a line vector .. Schunk! .. Is .. a and b plus displacement .. Calculate that - is going to be .. rotating numbers (unintelligible word) d .. So here we're .. in... incrementing .. delta X and delta Y .. Here we're .. incrementing .. by .. delta along .. like that .. So that I can do in any data path that I can find a square root in .. No, I don't need to find a square root - I need to find Z .. So once I've found Z .. I need to put in .. need .. Z .... <I'm just going out for a minute, can you keep talking?> Well I'll try to, yeah. OK. I need to calculate that. I can do that also .. by Z equaling .. sine .... I can do that also using trigonometry. So if I've got a Sine/Cos Generator somewhere else, I can do that without using a Square-Rooter .. So I don't need .. don't need to implement a Square-rooter. I can do that using sine and cos somewhere else - once .. and then once I've got sine and cos somewhere else, I can - having found Z - I can step through a coordinate system and find my locations in one part of the chip ....

00.32.26
(STATING PLAN) OK. Next ... So, I'm going to divide my chip down into a number of sections.

00.32.34
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT, SKETCHING FUNCTIONAL BLOCK DIAGRAM) I'm going to have a ... have a ... Sine.. /Cos .. Generator .. which I bung in .. x ... y .. get out .. theta .... Want to bung in theta, and get out.

00.33.11
(QUESTIONING SELF) What do I want here?

00.33.12
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) I want to .. bung in theta and get out x and y ...

00.33.20
(QUESTIONING SELF) Maybe I do need a Square Rooter!?

00.33.21
(STATING INTENTION) Let's go through this again.

00.33.22
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, READING DESIGN SPECIFICATION) The thing I need for that .. bunging in theta .... What an odd function! OK .. I need to bung in theta and get out ... It's the same as bunging in x over y. No it's not! .. x would be equal to .. You need to bung it in, theta - Why can't I have my Macintosh present? - Get out sine .. theta ...

00.34.08
(QUESTIONING SELF) Right, how can I use that to get ... and cos theta? ..

00.34.18
(GENERATING MATHEMATICAL SOLUTION CONCEPT) I can use that by dividing one by the other to get ..

00.34.21
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, APPLYING KNOWLEDGE OF HARDWARE CONSTRAINTS TO MATHEMATICAL SOLUTION CONCEPT) I don't want to do divisions if I can possibly help it! .. Still never mind .... OK. That's one module ....

00.34.41
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) Another module over here which calculates the coordinate system .... which I poke in .. X and Y .. and .. Z - which is related to those two ... and .. we get out .. little x and little y which is my .. step through coordinates. So now I take little x and little y .. Uh .... look up from the video store ... Out comes .. pixel value .. which I'm going need to do something funny with down here ... So I need to poke the pixel value ... So I also from this .. need to poke out .. into my Sine/Cos Generator. And down here I have a simple .... Right ..

00.36.40
(QUESTIONING SELF) Right. Have I done it?

00.36.42
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) I've got a Coordinate System Generator which takes in big X and big Y.. and Z - I suppose it will have to take in the other thing .. N .. M .. and oogamaflip .. in .. Somehow calculate Z - Worry about that later - .. Spits out .. on a regular basis x, y .. and .. what we might call theta .. Got a Sine/Cos Generator which I can buy ... Video line store which I can buy .. This thing ..

00.27.21
(GENERATING INTENTION) So .. What I need is .. Now to break down this block diagram ... into its constituent parts ..

00.37.35
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS) Coordinate System Generator .... I suppose .. I'm going to have to need some kind of .. Controller ... just to them that I've got everything (unintelligible here) .. which controls this

thing .. takes in START .. spits out COMPLETE .. just to tell somewhere, sometime that these are valid .. So I've got a Controller that takes in START .. kicks off my coordinate system, works out Z, then works out in a - rapidly as possible x, y and theta, on a one cycle basis .. looks that up here and here .. multiplies that out .. OK ...

00.38.25
(SELECTING SUBPROBLEM) Next ... So how to .. do that ...

00.38.38
(SPECIFYING PERFORMANCE CONSTRAINTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS) Right, in order to get .. the system to run fast enough to be .. well as fast as I can make it .. I can get a Sine/Cos Generator that outputs some new data on .. on every clock cycle for the system. I can get a video line store that outputs a new pixel on every cycle of the system .. Therefore I can run the accumulator flat out .. Therefore I need a Coordinate System Generator that works on every cycle ..

00.39.05
(QUESTIONING SELF) So, what do I need to do? ..

00.39.08
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS) I need .... a Coordinate System Generator circuit .. that spits out N, M and theta .. continuously .. Right .... OK .. So first of all theta - That's going to be dead simple. So that's going to be doing between .. one ..... Goodness only knows what it takes in! But .... it is going to be .... Register .. with ... a count in it .... Counter .... 0 .. to .. M .... Is it 0? or .. 1 ... And then it's going to get .. put into .... So that's the output theta .. I'm multiplying by .. some constant .. The constant is going to be equal to ... 360 divided by M .... Whack M in there .. It doesn't really matter - as long as I get something out there that's proportional to ... some numbering system .. So it's really M .. times a fiddle .. to get out .. something suitable to bung into a coordinate converter there .. So out of that I'll bung that into my .... out of there will pop {sine theta and cos theta} ....

00.42.34
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) Fine .... Right, that's going to be fairly simple ..

00.43.03
(SELECTING SUBPROBLEM) Now I need to trace through .... to go through something to do that calculation .. So now I'm going through the calculations of x and y coordinates ....

00.44.13
(SELECTING SUBPROBLEM, STATING INTENTION) So first of all let's calculate Z ..

00.44.16
(QUESTIONING SELF) So where's Z going to come from? ...

00.44.20
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS) Z equals ... Well if I can bung a theta in .... I know what a sine of theta is equal to .. But .. two ways - several ways of doing it .. One - a squared {plus} b squared, that's easy - square rooting it is not .... A Square-Rooter is a bit over the top .. Or I can just generate the square root by plugging through something. The other one - must be some way of using that Sine/Cos Generator to get .. Z .. putting in theta .... I don't know there is, unless I reverse the direction of it .. No! Use a Square-rooter ....

00.45.21
(STATING INTENTION) Right .. I want to design it in two stages.

00.45.24
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS) One thing to set up some initial numbers. That's easy. Generate a fiddle, and I multiply by M .. The fiddle's going to be related to something .. to do with the Coordinate Generator and .. 360 divided by M - to get the right number out of that. I may even be able to do it without a multiplier all together .. This one .. - calculate x and y look up - I need to calculate Z to start off with, so I'm going to need something to do a square root .. Don't know what .... Don't know whether that's practical, but we've got a Square-Rooter on an existing chip - so it must be fittable on our one .. to something .. something of a reasonable size ..

00.46.04
(STATING INTENTION) So .. let's concentrate on how I do .. these things ...

00.46.10
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF HARDWARE POSSIBILITIES TO MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICS) Got my Coordinate System Generator .. ah, trying to do the Coordinate System Generator at the moment. So here .... (unintelligible here) fixed, so I've got to get these xs and ys out .. So .... That's half way there .. I need to (unintelligible word) those equations .. So I need to do .. d divided by Z .. divided by - it's not! .... Dividing by Z is not a particularly pleasant thing to do .. So .. I have to multiply .. So the thing I need to do .. Dividing by is not particularly pleasant, so you need to manipulate this .. to get out .... something that doesn't need a division .... Multiply everything inside the brackets by Z, therefore I end up with .. b over Z .. times .. 1 .. times Z minus D .. that looks much nicer .. So that becomes a over .. Z times Z minus d ..

00.47.47
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) Right, much nicer to calculate ..

00.47.49
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, APPLYING KNOWLEDGE OF DETAILED HARDWARE POSSIBILITIES TO ABSTRACT HARDWARE SOLUTION CONCEPTS, MAKING NOTES, WRITING MATHEMATICAL EXPRESSIONS) So now .... I need to have something that can do division .. and something that can do square rooting .... Start up processor .. could either come from .. either .. from host - whatever that is .. or calculated .. on chip - as you seem fit - something that can calculate ... need to generate .. (1) .. Z equal to .... square root of that lot. I need to calculate .. then I need to calculate (2) a over Z where .. I'm going to need to have .. X over Z, and Y over Z. So that's my initial starting constants .. I need into the system ... and .. that should do it! .. So, let's assume it's done in a host .. because I'm lazy .. Hosts have divisions and square roots, so it's not worth putting those onto the chip .. I've managed to avoid doing that on the chip .. So .. I've now converted .. my chip into requiring inputs .... not .. N .... I know d - that's easy .... as well as .. other .. parameters ....

00.50.11
(QUESTIONING SELF) Right. How do we go from here? ....

00.50.26
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS, SKETCHING FUNCTIONAL BLOCK DIAGRAM) OK. The Coordinate System Generator now looks like this ....Takes in .... New .. x, equals b over Z .... (Z - d) .... and .... So how do I build that? - It should be fairly simple .. you need a .... Subtractor .... You need to generate that thing, which is d .. So that comes .... Right, initially if I shove ... a displacement .. of ... Better use the same processor here .. Right, I think .. absolutely certain that if I multiply by a over Z .... That's Z, that's d .. that's the distance, I know the distance, that's .. initially .. the first pass through .. that's going to be .... So that comes from something that starts off with .. M over 2 .... starts off with M over 2 .... and then .... a displacement here of .... and that .. over there ....

00.55.13
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) OK. It's got to be that! ...

00.55.17
(EVALUATING ABSTRACT HARDWARE SOLUTION CONCEPTS) Double it .... So, so far we're down to .... fairly simple architecture to get new x .. Double it for new y .. I've got .... I've got that to generate my .. coordinates ... I've got that going up to get my line store .. That going to my Sine/Cos Generator .. Right .. pixels go through that ...

00.56.16
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So my chip would look like .. chip would look like .... Inside the chip got a .... Right. Then we've got .. that takes in ... all the things I haven't really thought of .. the Control and (unintelligible here) .... and then .... g accum .... OK. Now coming back around there ..

00.58.39
(APPLYING KNOWLEDGE OF DETAILED HARDWARE CONSTRAINTS TO ABSTRACT HARDWARE SOLUTION CONCEPT) OK. So it all looks as though it will probably get on a chip .. That at the moment is about .... 50 percent of .... All the rest of it should fit on - the line store won't fit on .. the rest is all trivial ....

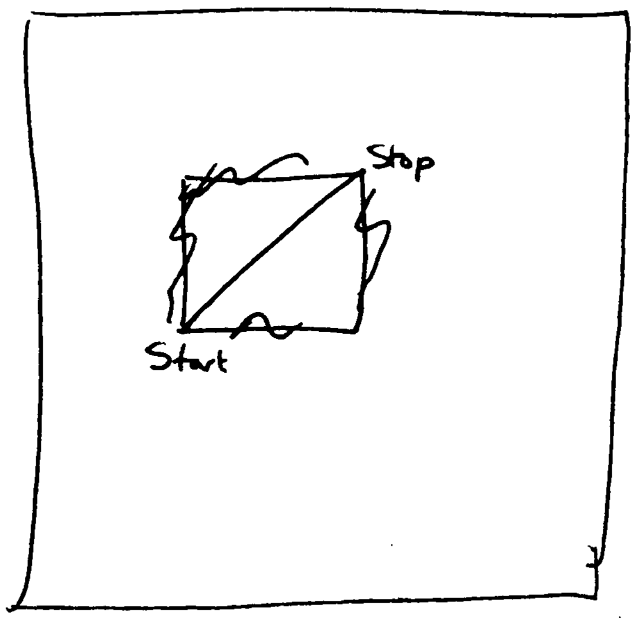
00.59.10
(QUESTIONING INVESTIGATOR) OK. I don't know when you want me to stop? <Uhm, well in a way where you think suitable - you don't want anything too detailed> Well, I've gone as far as enough bits of paper that you'll have difficulty following - enough scrappy bits of paper. Where do you go from here? I mean I've got, I've got <My problem is I'm not an engineer> Yeah, that's what I was guessing.

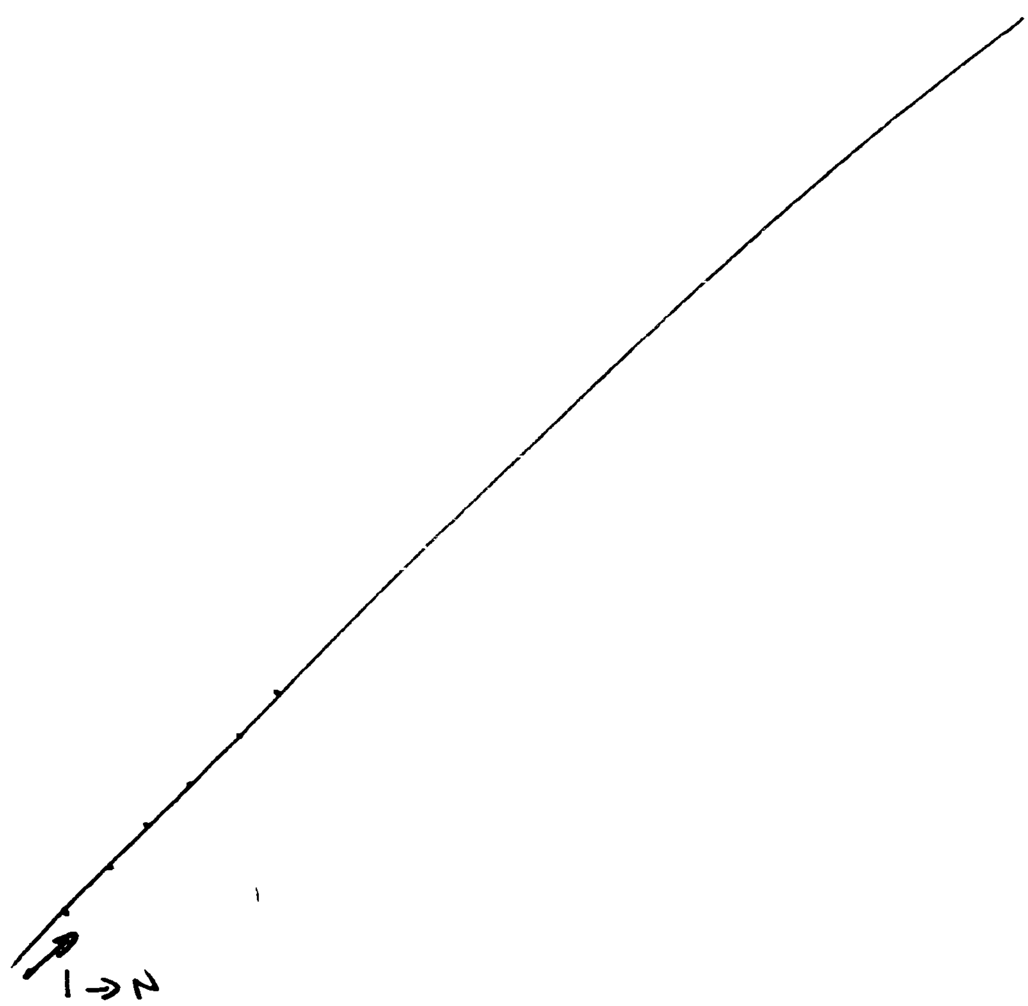
00.59.32

(Note: The following section of JF's protocol was not encoded since it was an essentially retrospective description of the design work that he had undertaken).

I've got a solution which is on several bits of paper .. So I run through it .. if I run through it with you standing there you might be able to understand it later on <OK, that's fair enough> The first thing was to try and figure out a coordinate system .. My math's is a bit rusty, so I .. what I normally do in designing a chip is .. is do this sort of thing - in any problem - is do this sort of thing one day, and I'll come back a day later, after I've had a night's sleep and figure out whether it's still right the next day .. So this is just my first draft of an idea rather than .. how I'd really approach an idea would be to go away now and think for .. overnight, and then come back the next day and do it again - as I was saying before. Right, so I came up with this system which .. enabled me to produce a chip that would work fast .. <You seemed to come up with it quite quickly as well, compared with other people> .. Well it depends what they're trying to do - it depends what your approach is. You said a high level approach .. so I've gone at a high level. I wanted a chip that would do something .. would access the line store flat out, and access the Sine/Cos Generator flat out, and hence produce this funny equation - which I can't think of any application for, but then I'm not into video processing .. Right, so I needed some way of generating coordinates that would step down that vector very rapidly and step up this vector very rapidly <You're obviously concerned about speed because it's a> .. well it's a chip .. vision processing - it's got to be fairly fast I assume otherwise you wouldn't be asking me to design it. So I made the assumption that you wanted it to access a line store as fast as possible .. and I can make a Sine/Cos Generator .. or at least C------ can .. that can access, you can access on, on a one cycle basis for a new sine/cos value .. several cycles later .. about 15 at the moment .. So I've got .. an answer - and I know that takes up about 50 percent of the chip - so I .. I know I've got a practical chip, 'cos 50 percent of it is sine and cos .. I can't get a line store on - so I've thrown that off the chip. So .. I can see how much I can fit on .. so at a high level I can see that I can fit it on .. then I wanted those things to run .. fast enough to make these things run flat out to make it practical .. so I manipulated the coordinate system to come up with some simple equations for generating .. xs and ys that can step down there - which is all this junk here .. and using that .. I ended up with a nice neat bit of paper .. where n and m were the new coordinates for a point related to a, b - the original ones - and d, which I assume were my starting points .. I also had Z as a starting point .. Z's a bit of a swine to calculate, so I threw that of the chip as well .. 'cos somewhere in here you mention a host. Host implies a processor - hence I can calculate these horrible square roots and .. little starting things that aren't worth putting on a chip - fairly easily on another chip. So I started off with Z - you could put that on chip .. could deduce something to calculate .. put my own little ALU on and .. square root things .. if I went away and got a text book .. so I could do that .. or the host can do it. I then tried to simplify that so I didn't have to do any divisions .. so I'm just doing a straight forward subtraction .. divisions and mult.. divisions are a pain in the neck .. So, I came up with a architecture - there you go - that just subtracted a number which I can calculate using another little data path which whizzes around and increments things .. multiply by a fiddle factor at the bottom, which I can deduce in advance .. I can get out new xs and new ys - I reckon one every cycle .. By inputing some coordinates .. by effectively inputing the sine and cos of theta - which was a previous bit of paper, which I'm not going to show you now - I've managed to eliminate sine and cos from the Coordinate Generator and get out new x and y with multipliers on each cycle .. so that's .. that part of the chip. Sin theta should be a similar thing .. there's one of those around here somewhere .. I reckon all I'll need is a counter .. to go between 1 and M .. and a multiplier with another fiddle, to make the output of here - which is going go .. which is going to step between 1 and M .. I need to fiddle that to some kind of - I don't know what the cordic process takes - its between 1 and 2 pie I should imagine - I need to fiddle something that goes in, between 1 and 2 pie and spits out sine and cos. I know that's possible at a high level .. so I don't intend to design it here because I haven't got the foggiest how to do it .. So I can do that. That gives me - going back to this page - those three .. I've got an accumulator here .. well that, to get that function out, you're basically just summing over a thing, so once I've calculated the sines from a Sine/Cos Generator - xi I can do by looking up in my pixel store .. I take them back to a straight forward accum.. multiply them together - that's a multiplier - and accumulate them .. and I drew something for that as well somewhere around here .. You're in (unintelligible here) trying to follow this lot .. Right, that's fairly simple to do .. it's there .. there you go .. multiply pixel by sine and cos, add them together and sum them and I can have them available as outputs here .. Then comes the really nasty low level problem. Assuming I've got this kind of architecture, now you've got to go in and actually design it in real gates .. because the next thing is how do you control it, how do you communicate with a host .. host isn't really defined here in any way. So now you come down to the real nitty gritty .. if I go any deeper I'm right in the thick of it now. I can see it's possible to do - I've now got to figure out how to control these architectures to actually cycle through, set them up. I've got to figure out how I'm going to tell the host that I've started and I've completed. So.. <So obviously what you find out by going in deeper could affect the design

at higher levels> It would yes, yeah, but I wouldn't have thought it would affect it that much - I know I can't get a line store on the chip, I know I can get a Sine/Cos Generator on the chip, I know I've put about 4 multipliers in here somewhere .. and 4 multipliers - I've had 16 multipliers on a chip - so if that's 50 percent of the chip, 4 multipliers is the other quarter - I'm just about in .. on one chip. So I have a chip that will do it. <It's not a bad solution in an hour is it>. Well, this is where the problems start though. From now on .. all hell breaks loose, 'cos I go and find .. I've got people who work for me who'd go into that chip, so I go and find somebody and say "I want a chip to do this, I've roughed it out .. build this sort of architecture - go for it!" Alternatively, I could sit down for three or four months and do it .. <Pretty good though. OK, we'll stop there, that's fine. That's a neat hour, that is. Thank you>.


Stop
Start


1 → N

Assum some requirement for accuracy of
- coordinate system let it be 8bits ?
hence total 16 bit system

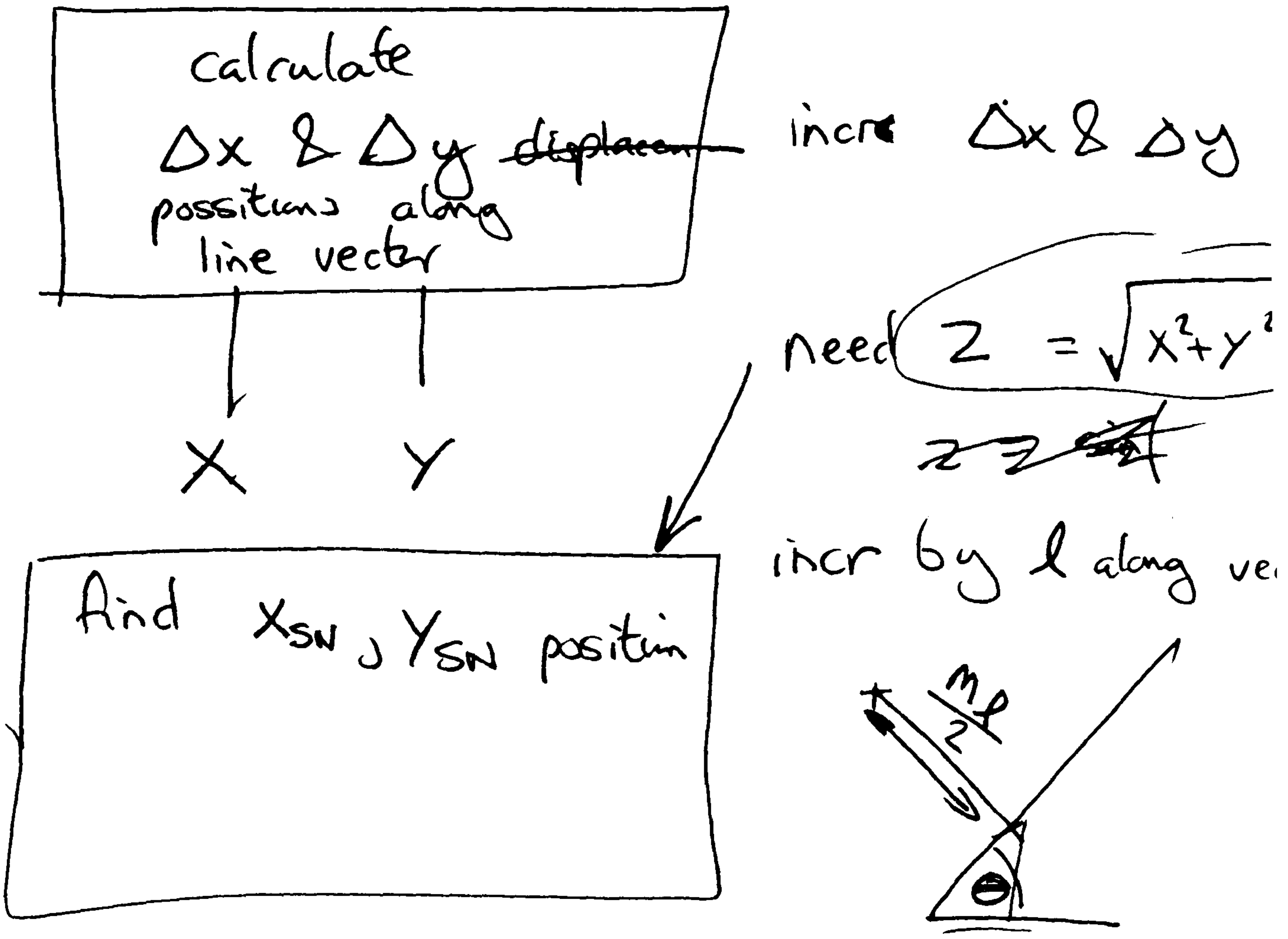
1) calculate mid point for normal vector

2) calculate starting ~~mid~~ point for normal vect

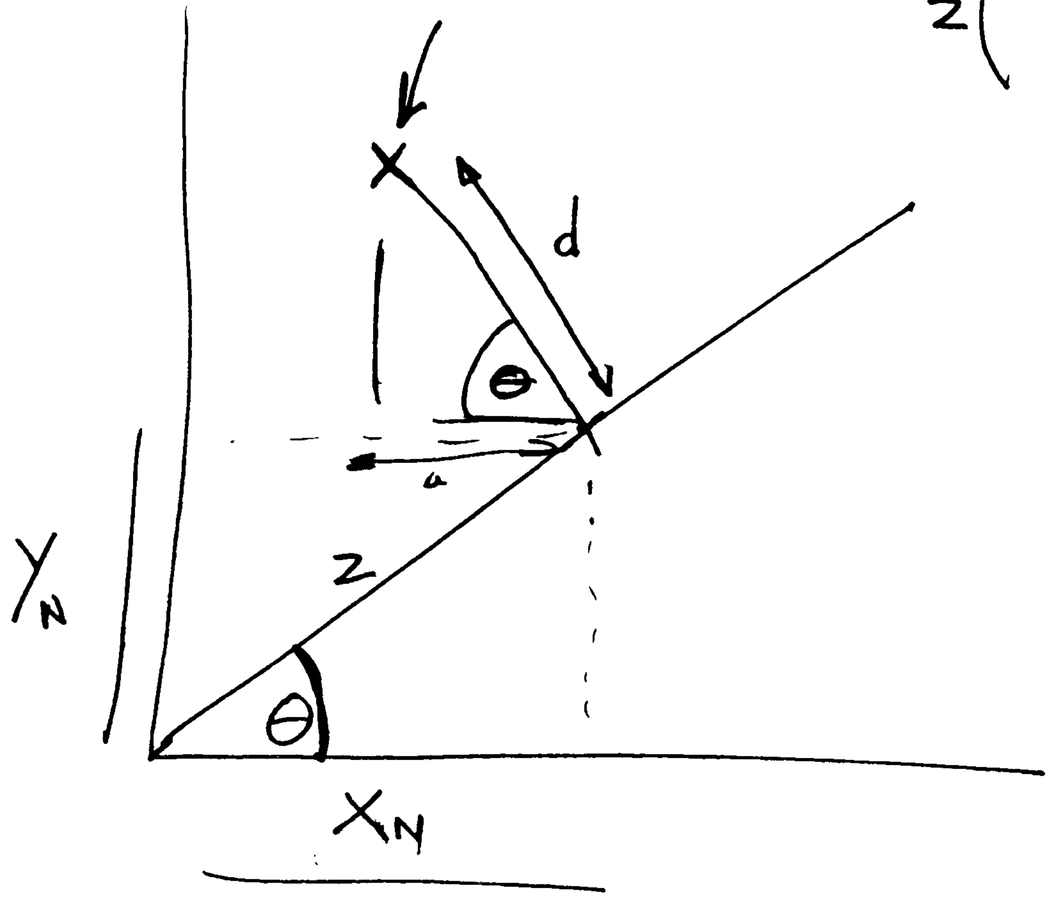
3) step through normal vector
performing calculation

How fast - beat a μP

will ~~alte~~ always be faster than μP
~~at~~ as sin & cos difficult to process


calculate
Δx & Δy ~~displacem~~
possitions along
line vector
X
Y
Find X_{SN}, Y_{SN} position
incr Δx & Δy
need Z = √(X²+Y²
incr by l along ve
$\frac{m l}{2}$
θ

$$x = X_N - \frac{d}{2}\left(1 - \frac{d}{z}\right)$$



$\sin = \frac{O}{H}$

$\cos = \frac{A}{H}$

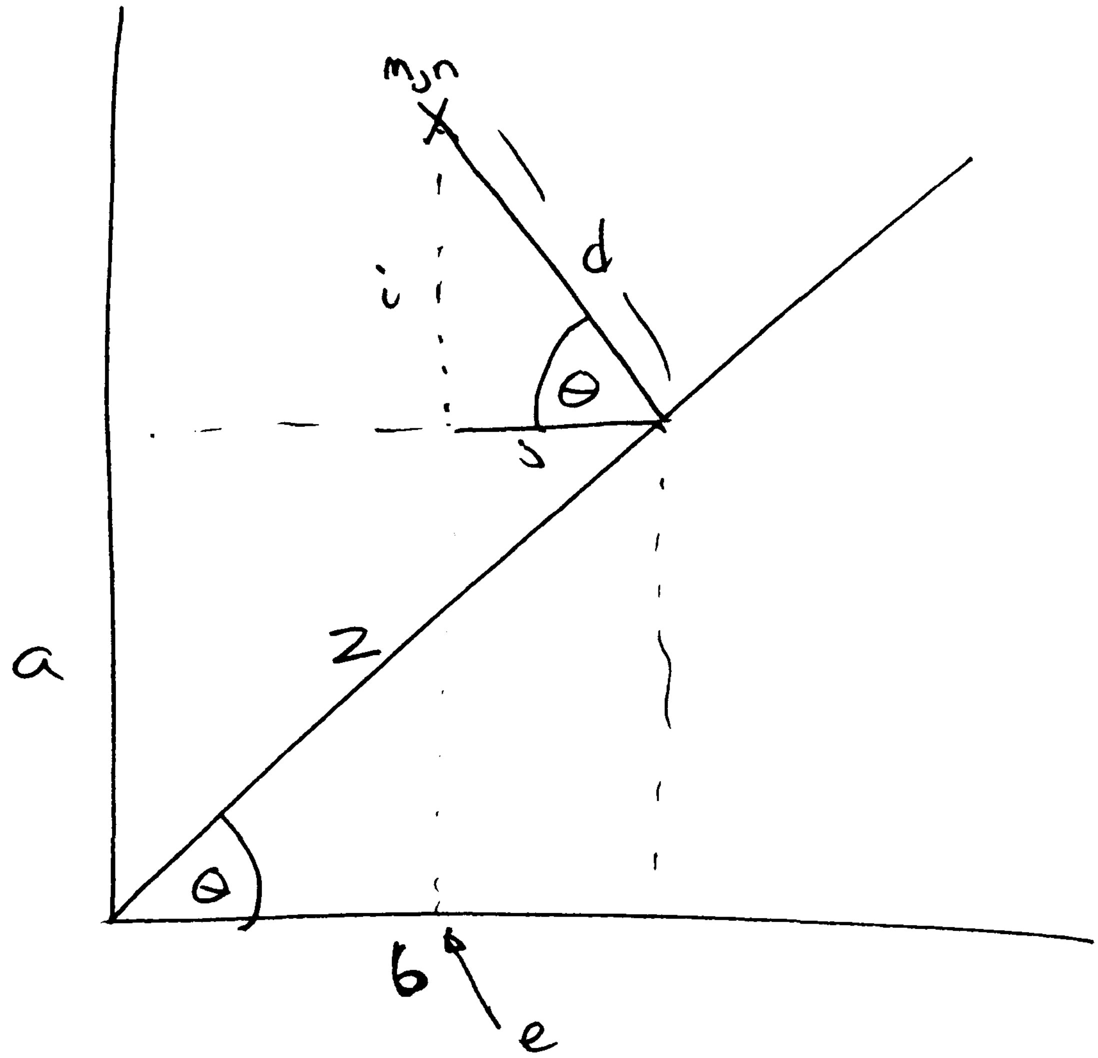
$\tan = \frac{O}{A}$

$$x = X_n - Y_N \frac{d}{2}$$

$$y = Y_n - X_n \frac{d}{2}$$

$$z = \sin\left(\frac{Y_N}{X_n}\right)$$

$a = \sin$

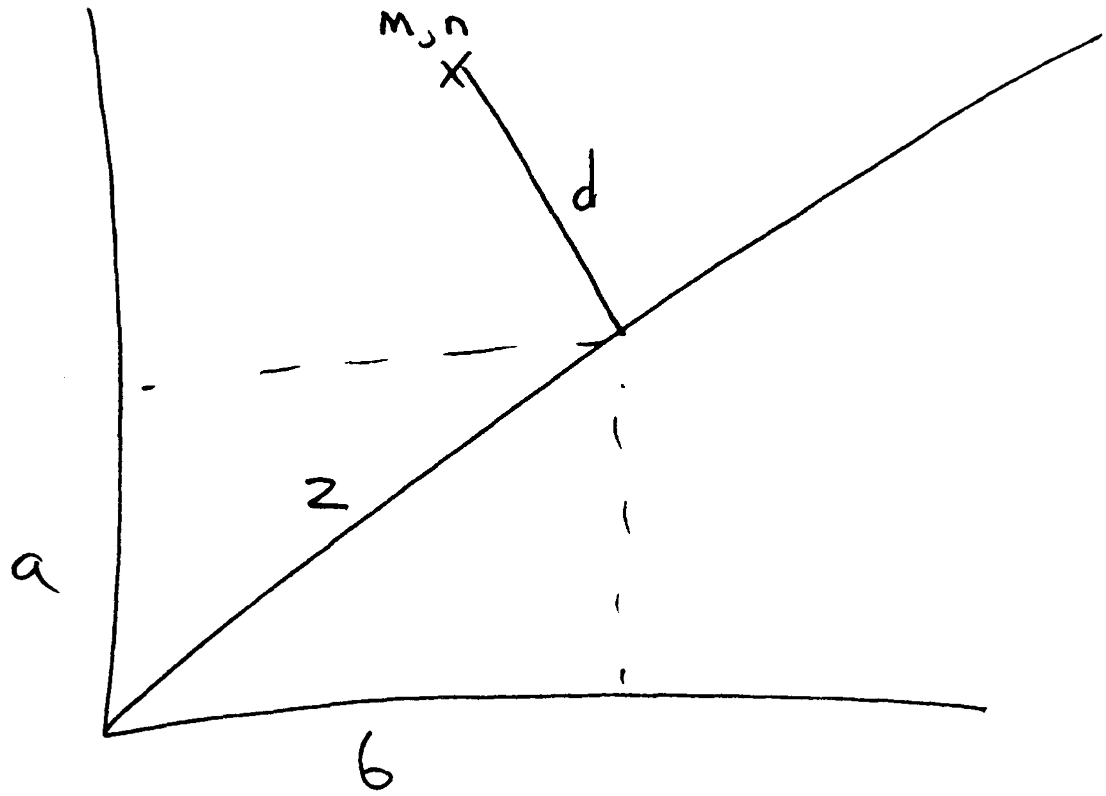


$$z = \sqrt{a^2 + 6^2}$$

$$\frac{j}{d} = \sin(\theta) = \frac{6}{z}$$

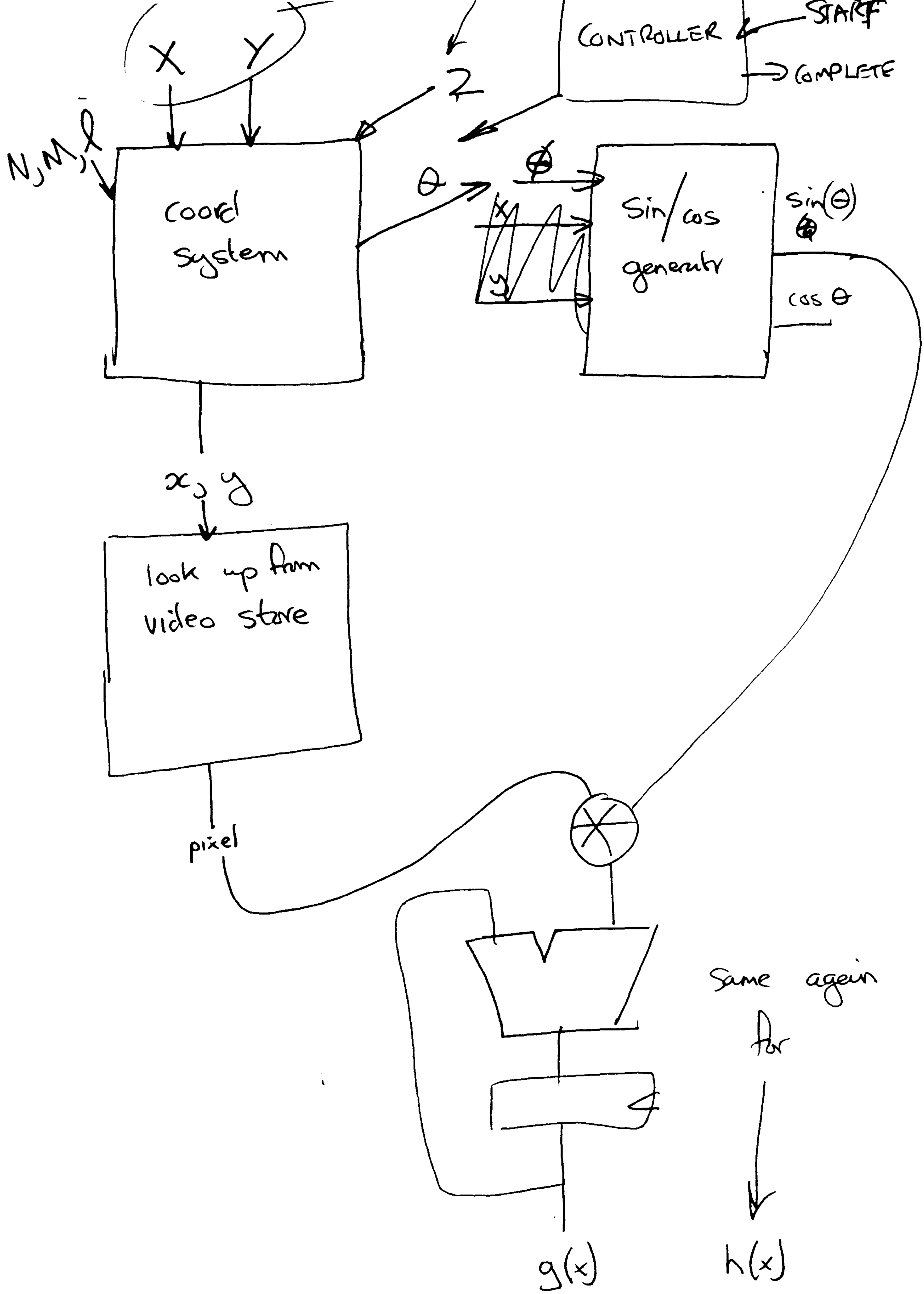
$$\therefore \; j = \frac{6 \times d}{z}$$

$$m = 6 - \frac{6 \times d}{z}$$



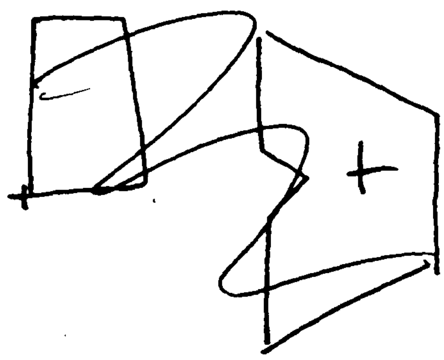
$$m = b\left(1 - \frac{d}{z}\right) = \frac{b}{z}(z - d)$$

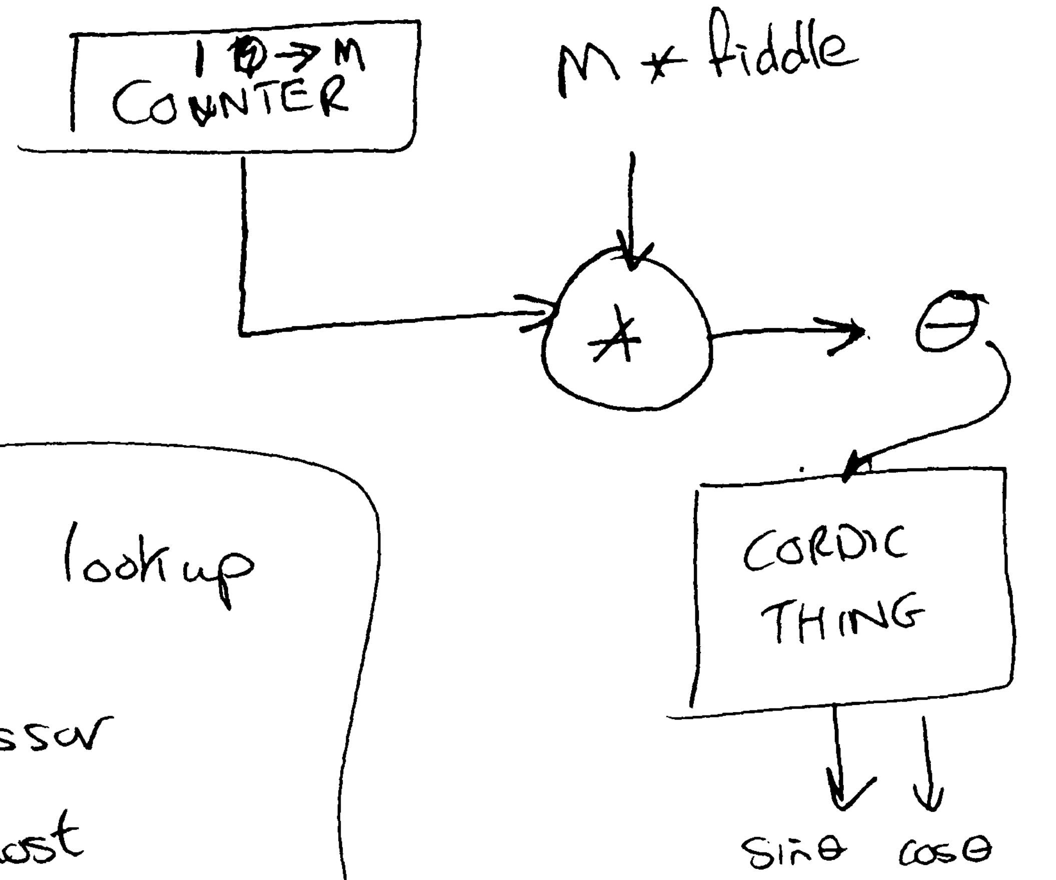
$$n = a\left(1 - \frac{d}{z}\right) = \frac{a}{z}(z - d)$$


X Y
CONTROLLER
START
COMPLETE
2
N, M, l
coord system
θ
sin/cos generatr
sin(θ)
cos θ
x, y
look up from video store
pixel
same again for
g(x)
h(x)

Coord system gen

$\bar{\theta}$





calculate x & y lookup

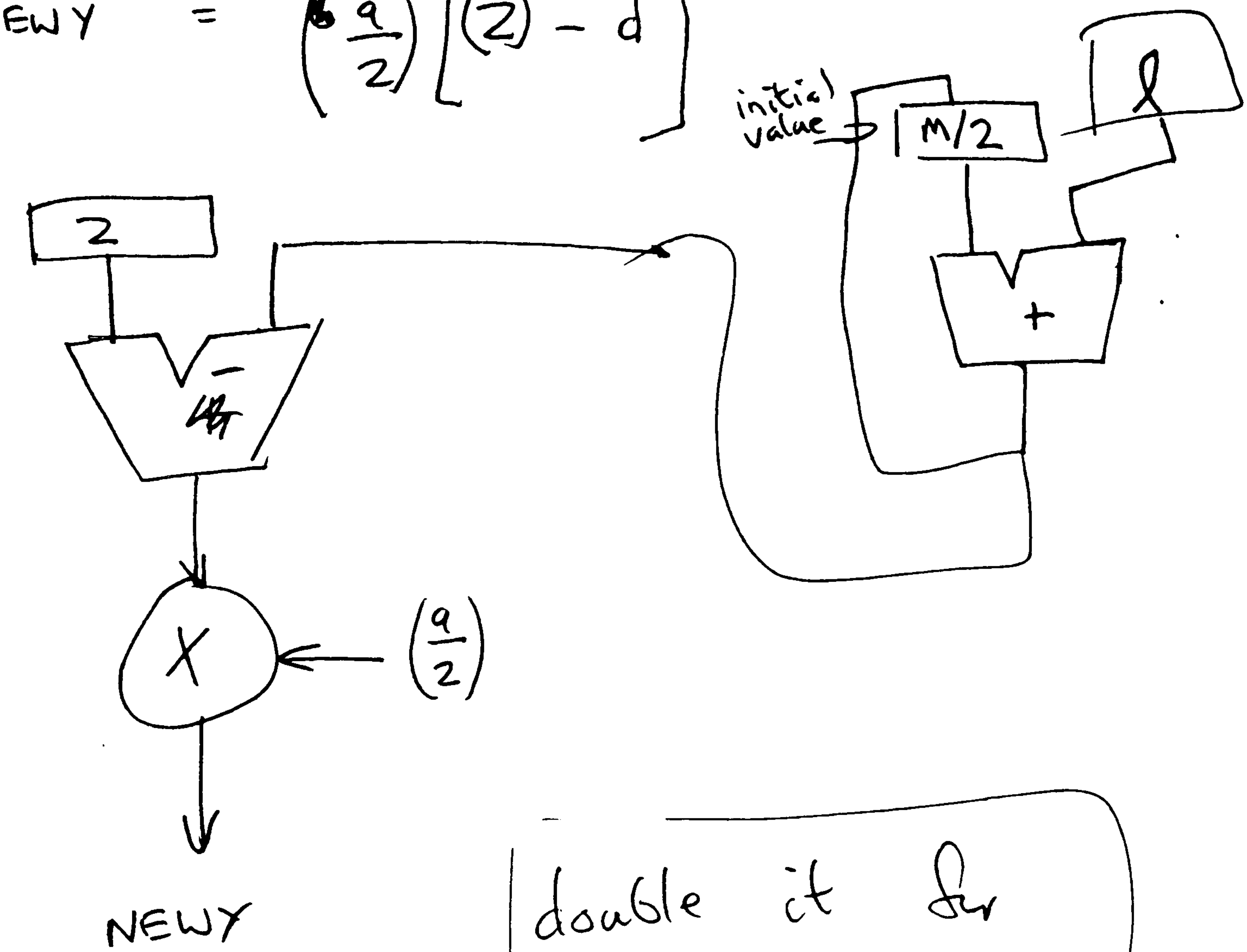
start up processor
either from host
or calculated on chip

1) $Z = \sqrt{x^2 + y^2}$
2) $\frac{X}{Z}$, $\frac{Y}{Z}$

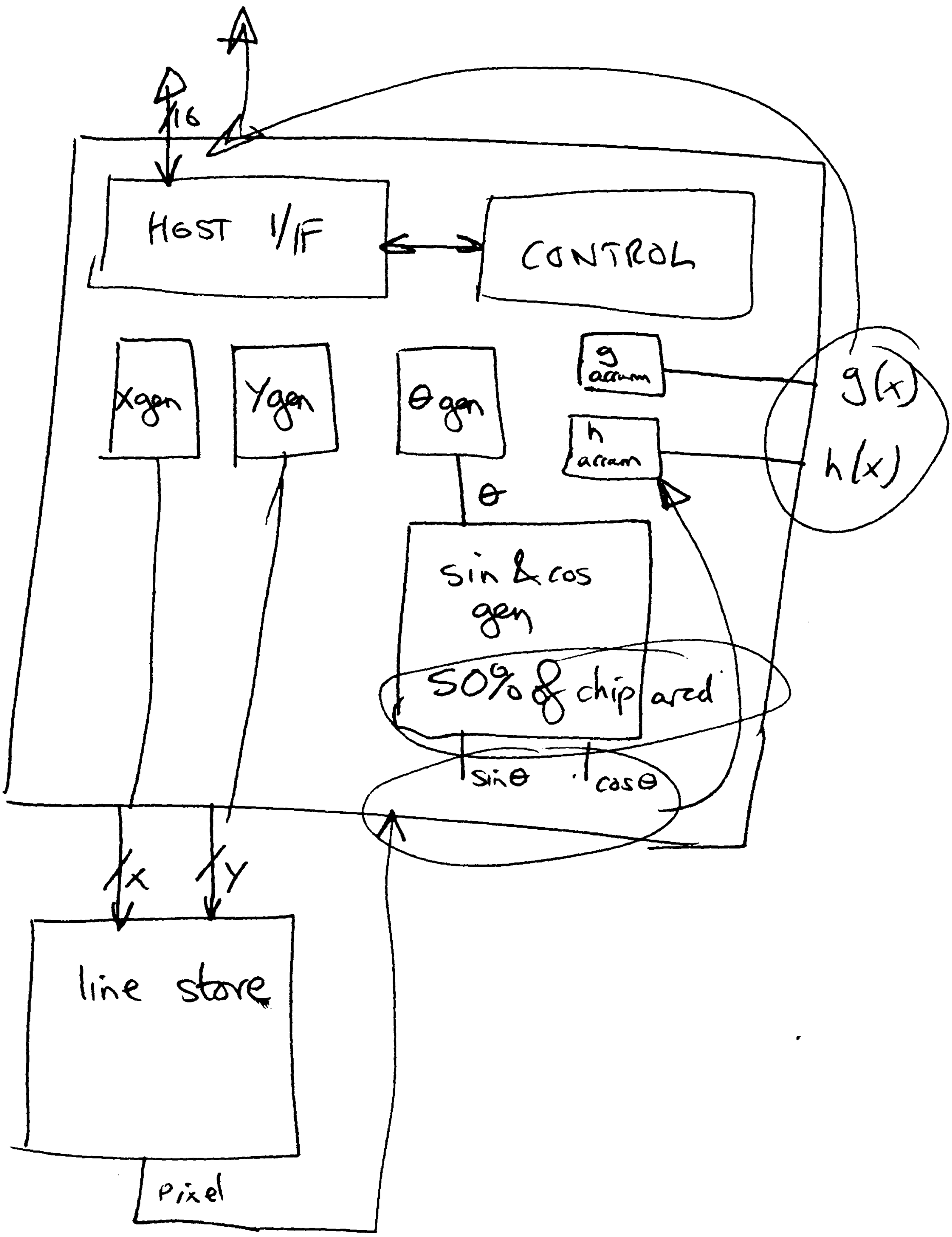
take these on to chip [illegible] as well as other parameters inputs ( ) to chip!

$$NEWX = \left(\frac{6}{2}\right)\left[(2) - d\right]$$

$$NEWY = \left(\frac{a}{2}\right)\left[(2) - d\right]$$



double it for NEWX


16
HOST I/F
CONTROL
Xgen
Ygen
θ gen
g accum
h accum
g(x)
h(x)
θ
sin & cos gen
50% of chip area
sinθ
cosθ
X
Y
line store
pixel

B.2.6. JC'S VERBAL PROTOCOL AND DESIGN WORKINGS

00.00.00
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) Right. OK. Process an area of RAM memory that contains a 2-D TV image. The chip will be be sent two X, Y coordinate pairs and constants N, M and 1 .. The coordinate pairs X, Y start .. and X, Y end .. define the position of a line vector drawn over memory. The chip then has to calculate N coordinate pairs along the line vector .... At each coordinate pair so derived generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .. Huhhh .... <experimenter prompt>

00.01.23
(EXPLAINING TO INVESTIGATOR) Oh sorry, I forgot. Right .... N coordinate pairs along a line vector .... Right. First of all .. trying to .. still trying to sort out exactly what I've got to do .. To decipher the math's ...

00.01.51
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) At each coordinate pair so derived generate .. the appropriate .. coordinates for a line vector drawn at a normal to the given line vector ... line vector drawn at a normal to the given line vector. Using a stepping factor .. N and M .... At each normal coordinate pair fetch .... fetch the nearest pixel from memory ....

00.03.07
(QUESTIONING INVESTIGATOR) Can I be quiet when I'm looking at the pictures or not? <It's best if you just keep talking aloud all of the time because you're obviously thinking something> Want a bet.

00.03.19
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) Right ..Refer to figure 1 .... Data is 8 bits deep and image array is at least 512 by 512 .... Right .... OK .... <Is it a familiar area?>

00.04.23
(EXPLAINING TO INVESTIGATOR) Uhm. Yes. Well I can see .. The problem is at the moment I can see the first bit is straight forward enough - generating .. uh, the coordinate pairs along the vector .. Uhm, because you can actually get an equation for the vector .. if you like - in terms of the start and the end points .. - should give you the constant .. But the bit I'm having trouble with is the, uhm ... seeing a way of deriving .. the, uh, the vectors of a normal .. Uhm .. It's not immediately obvious. I'm trying to think if there's any math's that I've .. should remember that's associated with that. I'm sure there is ... <Just keep chuntering through it> OK <and do try and speak as much as you can 'cos that's the only way I can have an insight on .. your ideas> OK <I know it's very hard - I understand> .. Right .... Uhm. Sorry I've dried up again haven't I .. Uhm .. I'm still thinking about this normal business ..

00.06.26
(ATTEMPTING TO RECALL) Uhm. I'm trying to remember the math's .. that gives you a vector normal to another one .. Uhm .... <Obviously it's quite difficult if you're trying to drag something out of memory> Yes that's right. Yes

00.06.44
(GENERATING MATHEMATICAL SOLUTION CONCEPT) .. Uhm .. OK. Well I think it's something to do with a vector product or something, whereby you multiply and sum and it all adds to nought .. So that should give you the normal vector .. Uhm. And then it should be a case of stepping it out I would have thought .... Uhm ..

00.07.08
(EVALUATING PROGRESS) OK. So I've got an idea for the first two.

00.07.11
(STATING INTENTION) Now for the third.

00.07.19
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS, UNDERSTANDING INPUTS) At each normal coordinate pair fetch the nearest pixel from memory .. and summate its value according to the expressions below .... Right .. M, N. Uh. Oh, hang on! .... 2, 3, 4, 5, 6, 7, 8 .... Fetch the nearest pixel .. from memory .... summate its value according to the expressions below .. generating two .. data items ....

00.09.14
(EXPLAINING TO INVESTIGATOR) Mmnh. I'm having trouble .. sorting through point three and seeing what exactly what it's getting at .. It's the math's that's in the way I think .... <Can you try as hard as you can to think aloud> OK <I know it's very difficult> all right. For each <You'll find that the more you try the easier it becomes> OK.

00.09.44
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) So I've generated .... generated a number of coordinate pairs .. and I've generated a number of coordinates .. normal to a vector .. And it's then saying .. for each one of those groups of coordinates .. you've got to perform some other arithmetic operation that's got sines and cos's in it ... and find the nearest pixel from memory for that all .... And then generate a .. a sum. That's a constant times .... sine term and a cos term .. M .... Mmnh ... xi .... Right. So the sine and cos terms are the same for each .. value of i .. because it's .. - Is that strictly true? .... No it's not .... So you have to have a number of sine and cos terms depending on the value of M .. and i .. No you haven't!

00.11.59
(QUESTIONING INVESTIGATOR) Is it all right to start drawing now? <Yes, sure> Is there any particular place in which it comes out best? <Uhm, just in the middle where you are, that's fine> OK <Yeah, I might sometimes have a look and focus you in .. You'll find it easier, actually, when you're working on paper to talk aloud>

00.12.13
(STATING PLAN) Yeah. OK. So I'll draw out the sine function because I know it's periodic and 360 .... And I'll .. do the same for the cos .. and see what sort of terms I'm going to have to have .... In chip ..

00.12.45
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, SKETCHING GRAPHICAL MODELS, WRITING MATHEMATICAL EXPRESSIONS) So the sine terms are going to come out as .. (unintelligible here) M .. is 5 .. for example .... So the .. sine 0 .. sine (360 over 5 .. times 2) .. times 1 rather .... and so on. Generally for the cos .. for cos 0 .. So that's going to be .. 0 .. is going to be 1 .. and cos 360 .... and so on ..

00.14.01
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So somewhere you are going to have to have .. those sine and cos terms stored .. in a look at table or ROM, or something like that .. Uhm. Now then

00.14.14
(COMMENTING TO INVESTIGATOR) <That's good. You seem to be finding it easier to verbalise now> Yes I've got into the swing of it <That's good> Uhm. OK.

00.14.21
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) So you need to define some sort of search .. as you've got to find the nearest pixel value from memory .. to each normal coordinate pair .... Oh, hang on a minute! ....

00.14.50
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) At each normal coordinate pair fetch the nearest pixel .. from memory and summate it's value according to the expressions below .... Ah! OK ....

00.15.14
(UNDERSTANDING FUNCTIONAL REQUIREMENTS) So you're going to have your 5 .. normal values that you've calculated .. and you're then going to have to search through for each of those values in memory - find the nearest .. and evaluate those sine terms .... So it will be a sort and a multiply .. uhm .. looking up from a look-up table holding the sine values .. and the cos values ....Uh. Right ... OK .... So .. Sine .. and cos values .... held in ROM .... Right .... OK. So we can calculate the N coordinate pairs .... And. Right .. Fair enough .. So .... We get the vector .. and do a vector .. subtraction .. from X-end .. Y-end .. X-start .. to Y-start .... Should give us ... a definition of the vector ....

00.17.35
(COMMENTING TO INVESTIGATOR) Sorry, you probably won't be able to read my writing. Does that matter? <No. No problem>

00.17.41
(QUESTIONING SELF, SKETCHING GRAPHICAL MODEL, MAKING NOTES) Uhm. Right. So generated a vector .... So is that the right way to go about it? - Do we actually need an equation? .... Mmnh ....

00.18.27
(ATTEMPTING TO RECALL) Oh. We have to dredge out the, uh .. vector .. maths from years ago. Uhm ..

00.18.35
(EVALUATING PROGRESS, EVALUATING MATHEMATICAL SOLUTION CONCEPT, QUESTIONING SELF) I'm getting a bit stuck now as to whether - That should give me .. That will give me a definition of a vector relative to the origin .. would be that .... Is that what I really need? How do I generate the coordinates along the line? - Got to have some way of relating it back .. to a start point otherwise I just translate it all back to the origin I think .... Mmnh ....

00.19.51
(EVALUATING PROGRESS, GENERATING MATHEMATICAL SOLUTION CONCEPTS) Right. Ah, hang on a minute! .. Rather than thinking about it in vectors .... Right. OK. I think that was a bit of a false start ... I can look at it in terms of lines really can't I .... Can I? Am I going to get the normal thing? Oh god! .... <experimenter prompt> OK .. I'm a bit stuck now as .. whether to go .. carry on .. with vector algebra - which I've.. most of which I've forgotten .. or .. whether that's the right place to start or whether it's .. go back and sort of y=mx+c .. equations .. Uhm ..

00.21.02
(STATING INTENTION) Let's have a look ...

00.21.07
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, GENERATING MATHEMATICAL SOLUTION CONCEPTS, ATTEMPTING TO RECALL) Somewhere along the line I need to get some form .. of equation where I can generate the intermediate coordinate pairs ... and I then think that the only way to get .. coordinates of .. uhm .. vectors .. at a normal to that is to somehow get back .. into vector format, so I can do the vector product which I think must equal 0 .. from what I can remember ..

00.21.37
(EVALUATING PROGRESS, EVALUATING MATHEMATICAL SOLUTION CONCEPT) Uhm .. I'm getting a bit .. a bit bogged down with this! - as to what I'm actually ending up with and whether that's the right way to go about calculating that .. vector .. Uhm ..

00.22.01
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS, SKETCHING GRAPHICAL MODEL) Right. So that's the origin ... and that's X-start .. Y-start .... You can say that that's vector start ... Now that's vector end .... And that's the actual result .... Ah .... So ....

00.23.22
(QUESTIONING SELF) What have I done there? ..

00.23.25
(EVALUATING MATHEMATICAL SOLUTION CONCEPTS) So that proves that that .... gives the result - that it's all shifted back relative to the

origin .... So that's always going to be a shift .... of X-end .. OK .... So that's what it will actually generate .. So I need to shift that up by .... the start vector to give me the real coordinates .. So I divide that .... Oh god, is this.. is this right!?! .... Yeah! OK .. So that .. gives me that vector there .. which I then need to shift .. with vector addition ... with .. X-start .. Y-start to give me the real .. coordinates .. OK.

00.25.09
(QUESTIONING SELF) So what have we got?

00.25.11
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS, WRITING MATHEMATICAL EXPRESSIONS) N is the number of coordinates: 1, 2, 3, 4, 5, 6 .. 7, 8 .... OK .... So basically .... for the end points ... then ... X-new is going to be .... Oh! .... Mmnh. Hang on a minute! .. Right. Let's use K .. We'll have a big N .. Mmnh ... Right .... X-end .. that's Y-start ... plus X-start .... X-new .... X-end ... X-start .... Y-new is going to be the same .... Y .. And that's going to be true for K equals 0 .. 0, 1, 2, 3, 4, 5, 6, 7 ... Ah! ... No .... Not quite true .. - Gives me the right .. start point .. gives me the wrong end point .... 1, 2, 3, 4, 5, 6, 7 .... That's better! It's got to be N - 1 .. So that should give me.. - that will be .... 1, 2, 3, 4, 5, 6, 7. Yeah. So that will split it into 7 chunks .... So you're incrementing by a seventh each time along here .. and then adding up X-start and Y-start to shift you back up .. to the right relative position ... That's the right way .. So you actually get the points in this line ..

00.28.44
(QUESTIONING SELF) So what have we got? ....

00.28.58
(SUMMARISING PROGRESS) So all these points are constant .... And these terms here .. are just going to be 0, 1, 2, 3 .. to N - 1 ..

00.29.31
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So you can have a counter .. multiplying by these terms which are constant and adding those terms which are constant .. So .. And that will spit out a new coordinate ... for each one .... OK. So that will produce .. the .... the end coordinate pairs.

00.30.00
(STATING INTENTION) So I'll just check the boundaries.

00.30.02
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, INTEGRATING MATHEMATICAL SOLUTION CONCEPTS) K is 0 That will be 0, so it gives you start .. K is N - 1 which gives 1 .. which means you can get rid of those .. which gives you the end points. So you've got all the points in between .. Now then .. So effectively .... Yeah .... You can generate those terms by .... first evaluating (X-end - X-start) .. (Y-end - Y-start) .... and adding in those.

00.30.59
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPTS, INTEGRATING ABSTRACT HARDWARE SOLUTION CONCEPTS) So you could hold those values in a register .... because they're not going to change .... So I presume that those coordinate pairs .... will be held in memory .... Two X, Y coordinate pairs. Well I'll assume that they're loaded in .. externally. So ... hold them in a register .... So say .. X-start .. Y-start .. X-end .. Y-end ... So .... These ... are going to ... subtract .... These .. are going to get subtracted as well .... So that gives us X-end .... minus X-start, Y-end .. Oh bugger! Yes all right then .. got these the wrong way round .... OK .. So .... Now those terms are all going to be .. multiplied by the output of a counter that's just going to go 1, 2, 3, 4 .... So we can do this .... Gives us these terms and they're going to fall out of there ... into an adder .... Where that's going to be the value .. of X-start ... that's going to be the value of Y-start. That coming out there will generate your terms ... Ignoring any control at the moment - just having a look at the arithmetic units .. Right .. So that will give you .. Y-new .. and X-new .. So .. Now then .... I guess the thing to do would be to load those into RAM somewhere .. and then you start crunching through the ..

00.35.19
(QUESTIONING SELF, EVALUATING MATHEMATICAL SOLUTION CONCEPTS) Or do we need to do that? Do we need them again? ..

00.35.24
(READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) At each coordinate pair generate the appropriate coordinates for a line vector drawn at a normal to the given line vector .... OK .... So they will need scaling as well ....

00.36.11
(GENERATING ABSTRACT HARDWARE SOLUTION CONCEPT, MAKING NOTES) We can scale the output with a counter .. so that everything is divided by N - 1 .. Then we get the correct values in there, and the correct values coming out ... Uhm ... OK ...

00.36.39
(SELECTING SUBPROBLEM, READING PROBLEM SPECIFICATION, UNDERSTANDING FUNCTIONAL REQUIREMENTS) At each coordinate pair generate the appropriate coordinates for a line vector .. drawn .. at a normal to the given line vector .. Uh ... OK ..

00.37.00
(UNDERSTANDING FUNCTIONAL REQUIREMENTS, SKETCHING GRAPHICAL MODEL) So .... We have .. back to this diagram .... That's the end vec.. that's the origin ... Start .... That's the result vector. So we now want something normal to that .... OK .... So we know the values of that .... This is going to be .. X-end .. X-start ... and Y-end minus Y-start .. So .. It's again .... Using .. the stepping factor .... Coordinate pairs ... Stepping factor .... Right ... Uh ....

00.39.46
(QUESTIONING INVESTIGATOR) Can I draw on the piece of paper you gave me or not? <Yeah>

00.39.49
(UNDERSTANDING INPUTS, UNDERSTANDING FUNCTIONAL REQUIREMENTS) Yeah. Right well I'm going to assume in that case that ... that funny squiggle, whatever it is - a lambda or l - is that distance there .. The stepping factor - I don't see it anywhere else .... I'll assume it's that distance. Now then ... I can generate .. a vector that's a normal to that vector .. mmnh, the vector product thing .. So .. vector product ....

00.40.35
(ATTEMPTING TO RECALL) I think .... Think back to what it actually means ....

00.40.50
(GENERATING MATHEMATICAL SOLUTION CONCEPTS) I think that that equals 0 ... and ab .. vectors ab and cd are normal .. So .. given one and you know it's 0, you can say that .. ac .. must equal minus bd .... So .... You know a and b ... You don't know c and d ....

00.41.42
(QUESTIONING SELF) Have I done that right? ....

00.42.10
(EVALUATING PROGRESS, EVALUATING MATHEMATICAL SOLUTION CONCEPTS, EXPLAINING TO INVESTIGATOR) I'm getting a bit .. a bit stuck here now ... Uhm .. I think .. I think that, uh, I've got the right vector algebra .. I think, - vaguely .. Uhm. But it's a matter of .. deriving .... deriving the values for the normal vector .. which then should just be a case of stepping out .. Uh. But I'm not quite sure how to go.. go about that ....

00.42.53
(GENERATING MATHEMATICAL SOLUTION CONCEPT) I think it basically means that you .... the ratios have got to be the same .. and from that you can say that .. (a over b) .... is minus (d over c) .... Uhm ....

00.43.52
(EVALUATING MATHEMATICAL SOLUTION CONCEPT, EVALUATING PROGRESS) I'm sure there must be something simple that I'm missing out on! .... So that's going to be at right angles as well .... Now then .... Maybe I've gone about this in the wrong way!

00.45.02
(GENERATING MATHEMATICAL SOLUTION CONCEPT, SKETCHING GRAPHICAL MODEL) Let's take the first point I've calculated ... That would be ... say for .. M equals 1 .. We would then need to derive the normal .. to that vector ....

00.45.45
(QUESTIONING SELF) So what have we got? .... How do you go about getting that? .... Well you've got that point .... And you need to find these ..

00.46.47
(QUESTIONING INVESTIGATOR) Can I go and get a math's book? <yeah> Mmnh,

probably haven't got time now have I! Riffle through and brush up on my vector algebra! Uhm .. Right .. <The only stuff I've got there is trig' functions .. On the side> Is it? Ah! ...

00.47.07
(SETTING INTENTION) Have a quick scan through this ....

00.47.56
(QUESTIONING SELF) I know that length .... Do I know that length? .... Do I know any other lengths? Ah! .. Hang on! If I know that length nd I know that length ... Is that going to help? .... Uhm .... Mmnh. I don't think it is, or is it? .. If I know that .... So that's known .. and .... Oh! .. Christ! .... Uhm ....

00.49.36
(STATING INTENTION) Let's just try that again ....

00.49.52
(GENERATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL) Start .. That's the origin .. So I now go into this point .... So .. we know ... We know that length .... So that's parallel to that .... So that's going to be a right angle, and that's going to be a right angle .... So I've got to get .. these 5 points somehow .. That's the normal vector ....

00.52.23
(QUESTIONING SELF, GENERATING MATHEMATICAL SOLUTION CONCEPTS, SKETCHING GRAPHICAL MODEL) How am I going to do that? .... <experimenter prompt> Yep. Sorry, I forgot ... OK. So we say that's .. that's the normal vector there .... So .... How do we?.. That's somehow got to get shifted along .... That one up here all down here .. which will just be shifted relative to .... relative to each increment .. in X and Y as you go along .. So .... Mmnh ... So i guess it goes back to this .... How do you find a normal? ....

00.55.04
(EVALUATING MATHEMATICAL SOLUTION CONCEPT) Nope! ... That must be it! ....

00.55.34
(COMMENTING TO INVESTIGATOR) I think we're going to have to call it a day there, I'm afraid.

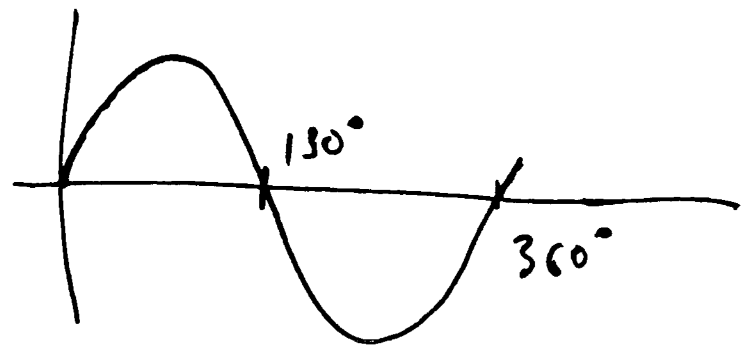
00.55.37

(Note: The following section of JC's protocol was not encoded since it was an explanatory account of why he was having difficulty with his design work which was provided for the experimenter's benefit).

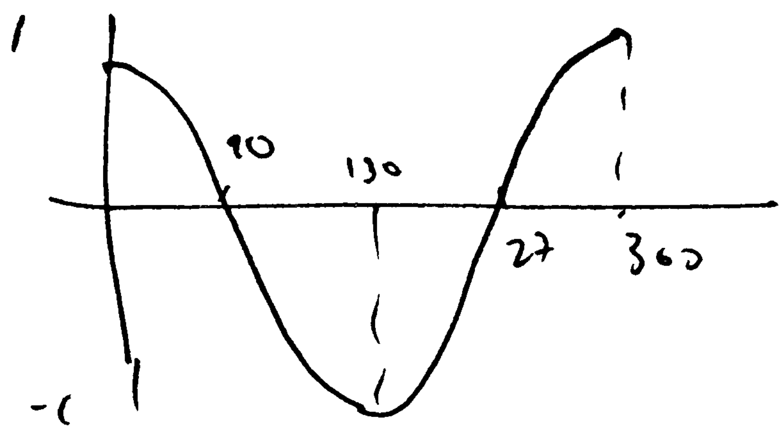
<Are you having difficulty> Uh, yes! .. <What, with the mathematics?> Uhm, Yeah. I've got really bogged down with, uhm ... Essentially I've gone through. I've.. I think I've .. The first bit is straight forward enough .. The second bit I'm having trouble with .. uhm, because I can't

see it in, uhm, in terms of math's, uh, so I can't map that back in.. in terms of, uhm, you know sort of like a hardware implementation in terms of arithmetic units. I'm getting bogged down. I.. I think the way to do it is to.. is to somehow find the .. the normal vector, and I think that that's the way to do it, but I'm not one hundred percent sure, and I'm a bit sort of stuck as to well, you know.. That ration seems fairly arbitrary .. and .. whether you just calculate .. that and set one to 1 .. I don't know. And then I'm not sure how .. OK I end up.. I know that will give me a normal vector .. I think it will be relative to the origin, but I then need to map that somehow into real coordinates. I'm having trouble first of all, you know, sort of saying 'OK what values do you actually put in there' .. and then how exactly do you shift that across to the.. Because effectively you're going to like repeat that little vector, uh, at a number of points along this line to give you your.. your, uh, your points at the normal here. I'm having trouble mapping that across . The way which I've gone about it really is to look at the math's first .. and see what it's like in terms of, you know, uh, summations and multiplications, and I could see directly from that one that .. effectively you're going to multiply by 0, 1, 2, 3, 4, 5 et cetera, although it would be scaled by .. uh, a number. So you could.. you know, I can see a way of getting that out in terms of hardware - very roughly. But I really got stuck on this one. <Well that's OK. You've taken it as far as you can. Obviously you need some math's books really> Yes I need to know some math's, yes .. OK. The other thing well is the stepping factor. I made the assumption that it was that .. that distance there <It is - I think so>

sin x



cos x



Sin and
cos values
held in ROM?

$M = 5$

$\sin\left(\frac{360}{5}\right)$

$\sin 0 =$

$\sin\left(\frac{360}{5} \times 1\right)$

$\sin\left(\frac{360}{5} \times 2\right)$

⋮

$\cos 0 = 1$

$\cos\left(\frac{360}{5} \times 1\right)$

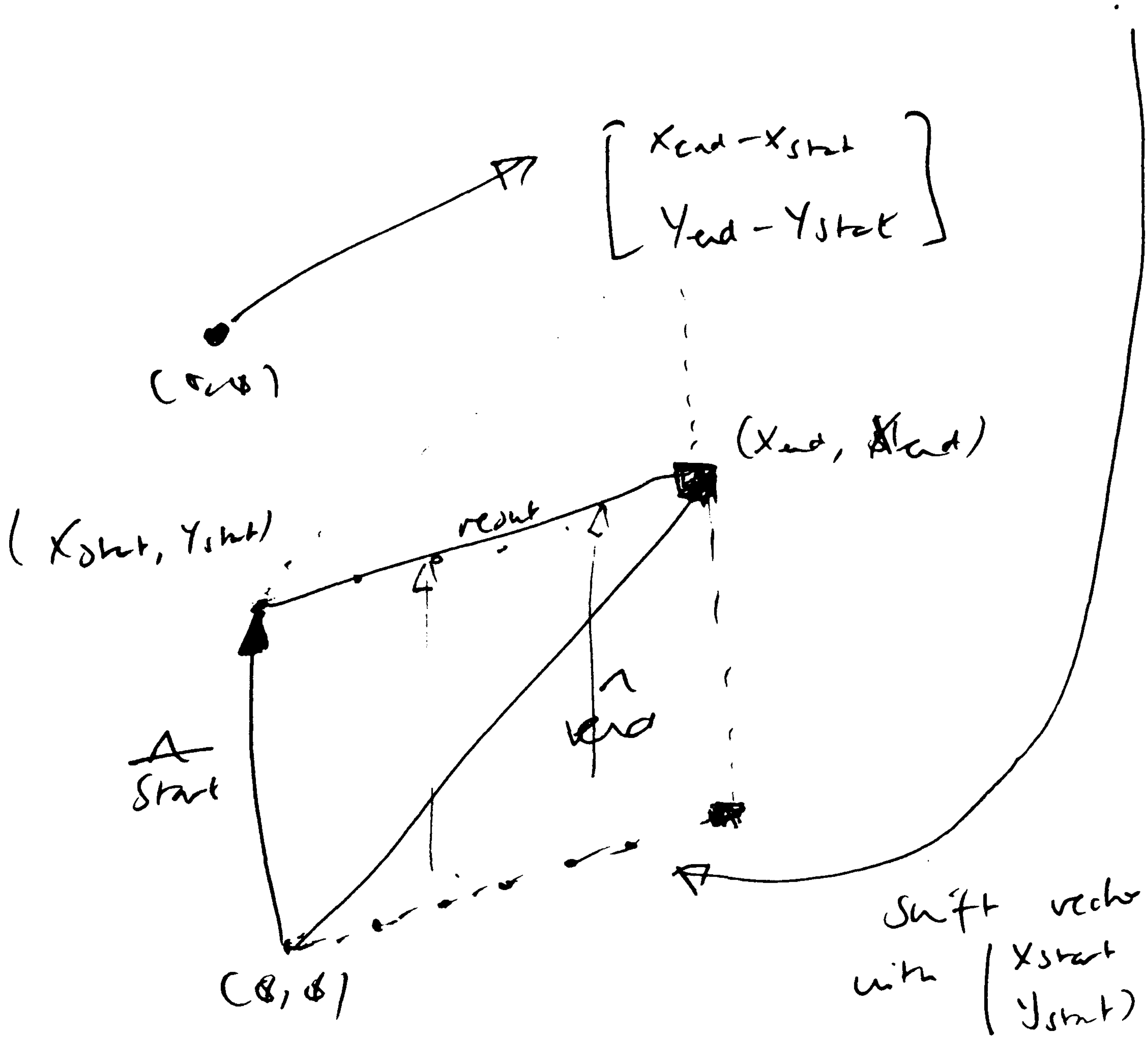
$\cos\left(\frac{360}{5} \times 2\right)$

$\cos\left(\frac{360}{5} \times 3\right)$

⋮

(1) Calculate N - co-ordinate pairs

$$\begin{bmatrix} X_{end} \\ Y_{end} \end{bmatrix} - \begin{bmatrix} X_{start} \\ Y_{start} \end{bmatrix} = \begin{bmatrix} X_{end} - X \\ Y_{end} - Y \end{bmatrix}$$



For N points

$$X_{new} = \frac{K}{N}(X_{end} - X_{start}) +$$

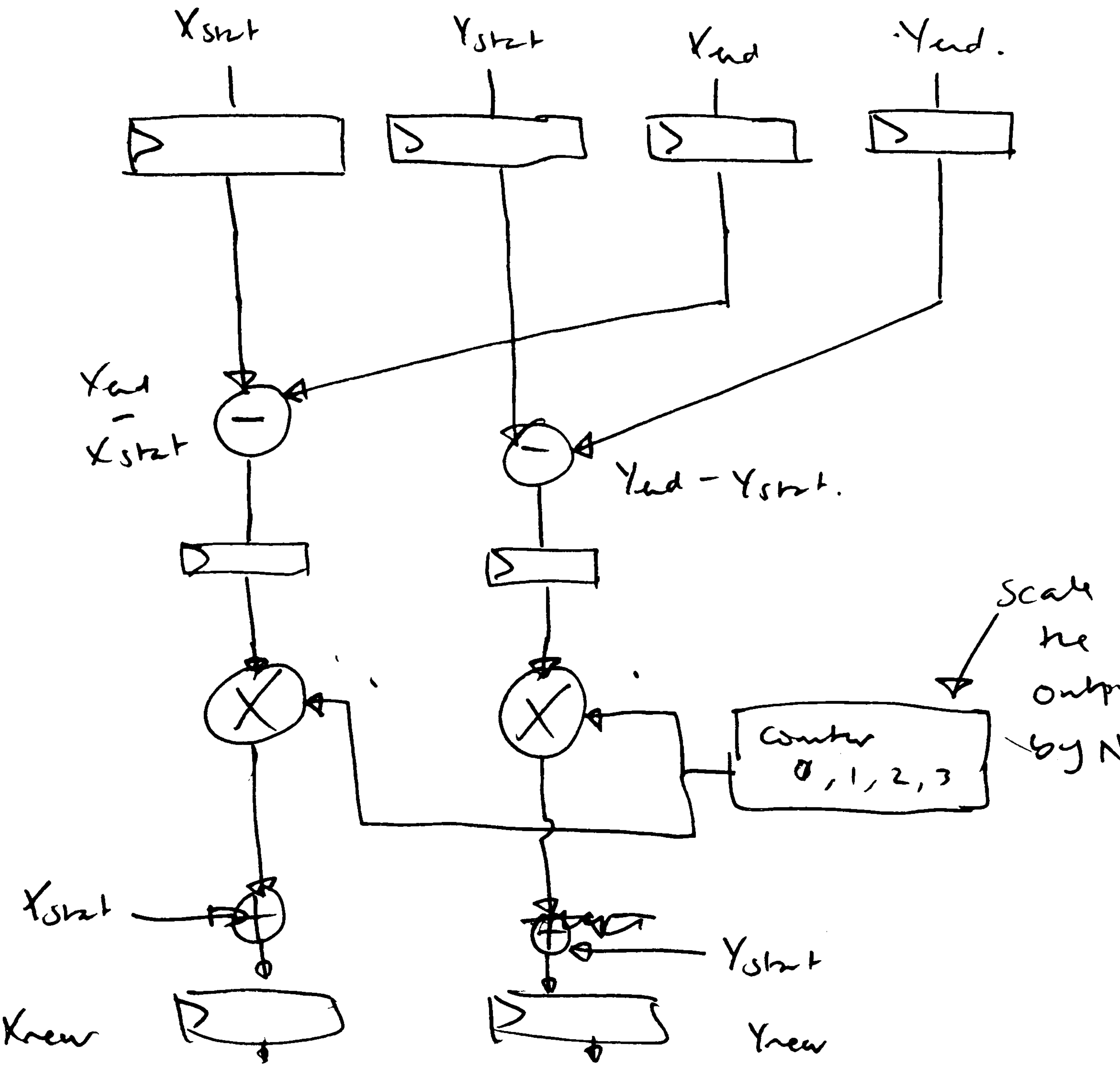
$$X_{new} = \frac{k}{N-1}(X_{end} - X_{start}) + X_{start}$$

$$Y_{new} = \frac{k}{N-1}(Y_{end} - Y_{start}) + Y_{start}$$

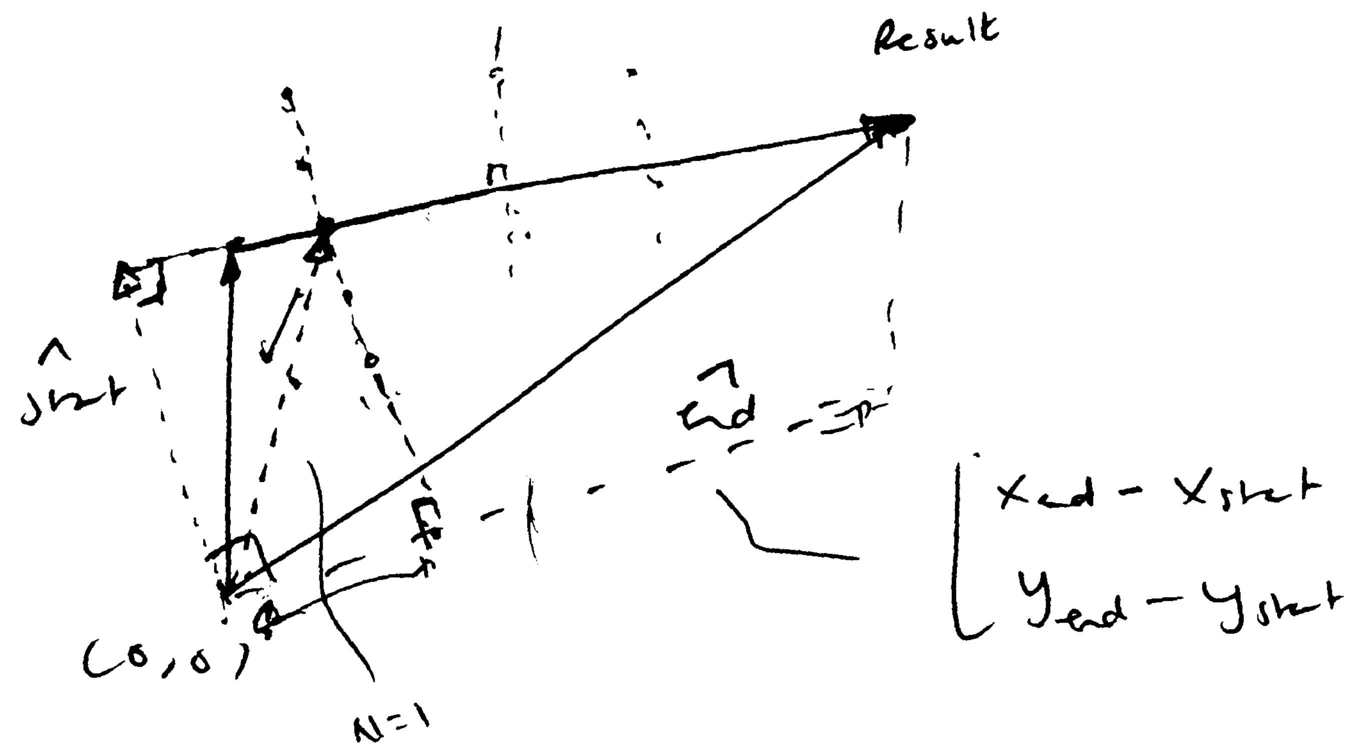
$k = 0 \rightarrow N-$

const. const. constant

0, 1, 2, 3 . . . N-1



(2)



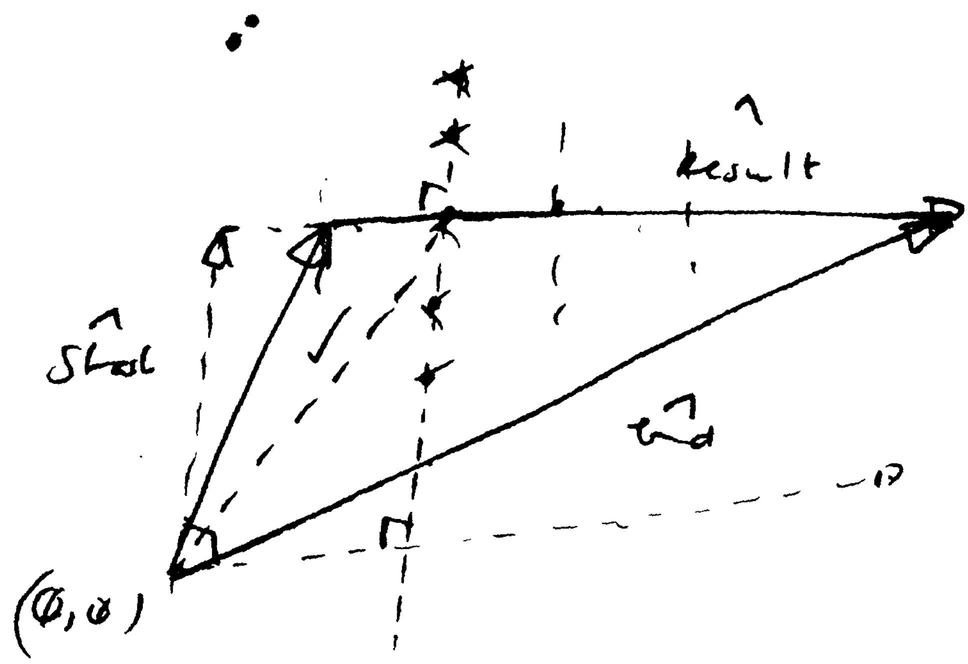
$$\begin{bmatrix} a \\ b \end{bmatrix} \cdot \begin{bmatrix} c \\ d \end{bmatrix} = ac + bd = \emptyset$$

then $\begin{bmatrix} a \\ b \end{bmatrix}$ and $\begin{bmatrix} c \\ d \end{bmatrix}$ normal

$\Rightarrow \quad ac = {}^{-}bd$

$\Rightarrow \quad \boxed{\dfrac{a}{b} = -\dfrac{d}{c}}$

FIND THE NORMAL VECTOR.


Result
Stud
End
(Φ,θ)

Appendix C

Intervention Study

Appendix C. Intervention Study

Page

Your company's senior design engineer has selected you to carry out the design work for this client and has given you some technical information on acoustic curves as well as a set of potentially useful data sheets regarding common types of transducers, operational amplifiers, microprocessors etc. If you prefer not to use these specified components and devices, however, then it is perfectly acceptable for you to come up with technical ideas of your own.

This superior has given you an hour to come up with a basic design solution which he will then be able to evaluate. He has suggested that if you feel that any of the design requirements are underspecified then you have free rein to fill in with sensible ideas of your own.

Your immediate task, then, is to come up with a basic design for this sound level monitoring instrument.

NOTE

Please follow all experimental requirements mentioned in the instructions carefully. They are important.

C.1.2. EXPERIMENTAL INSTRUCTIONS

Subjects were presented with one of the following sets of written instructions depending on the experimental condition to which they had been allocated.

INSTRUCTIONS FOR SUBJECTS IN GOALS CONDITION

In this study you are required to tackle a design problem which has been devised to be well within your range of ability and technical understanding.

You have approximately 1 hour to pursue this design and you have been provided with a variety of technical data that may be of help to you. Please attempt this problem using your preferred strategies and methods of working. You are requested to design in silence and to carry out your design work on the blank paper provided. You are reminded that while your design ideas will be assessed your anonymity is assured at all times.

Please note that this study involves a procedural manipulation that it is essential you adhere to. At 10 minute intervals throughout the study a bell will be sounded. When this occurs cease your design work, take a sheet of the specially formated paper and very briefly
WRITE DOWN THE GOALS THAT YOU ARE
CURRENTLY AWARE OF PURSUING WHICH RELATE TO YOUR DESIGN WORK.

For example, if you were working on a problem involving the design of a power supply system you might at some point be aware of pursuing the following goals:

> GOALS THAT I AM CURRENTLY AWARE OF PURSUING.
>
> I am aiming to select and interconnect on paper the components that I think I need in my 'switch-mode' power supply system.
>
> At the moment I want to calculate the transformer currents so that a suitable transformer can be designed.
>
> I also want to choose a fast switch that is compatible with the desired mode of operation.

You will have 2 minutes to write down the goals relating to your design work. The end of this 2 minute period will be marked by the sound of the bell, at which point you should resume your design work. If you have completed writing down your goals before the end of the 2 minutes then resume your work prior to the sounding of the bell.

If any aspects of these instructions are unclear to you then please attract the attention of the investigator by raising your hand.

INSTRUCTIONS FOR SUBJECTS IN RATIONALES CONDITION

In this study you are required to tackle a design problem which has been devised to be well within your range of ability and technical understanding.

You have approximately 1 hour to pursue this design and you have been provided with a variety of technical data that may be of help to you. Please attempt this problem using your preferred strategies and methods of working. You are requested to design in silence and to carry out your design work on the blank paper provided. You are reminded that while your design ideas will be assessed your anonymity is assured at all times.

Please note that this study involves a procedural manipulation that it is essential you adhere to. At 10 minute intervals throughout the study a bell will be sounded. When this occurs cease your design work, take a sheet of the specially formated paper and very briefly
WRITE DOWN THE RATIONALES UNDERLYING
YOUR RECENT DECISIONS TO KEEP OR REJECT TECHNICAL DESIGN OPTIONS.

For example, if you were working on a problem involving the design of a power supply system you might at some point have made decisions based upon the following underlying rationales:

RATIONALES UNDERLYING MY RECENT DESIGN DECISIONS

I have chosen an IC to control my power supply rather than using discrete components because it is cheaper and easier to do and there's no point in reinventing the wheel.

I have decided to use a bipolar transistor rather than a MOSFET because no additional circuitry is required to interface it to my chosen controller IC.

I have selected a polypropylene capacitor for the tuned circuit because it has very low losses at the frequencies involved and it is not too expensive.

You will have 2 minutes to write down the rationales underlying your design decisions. The end of this 2 minute period will be marked by the sound of the bell, at which point you should resume your design work. If you have completed writing down the rationales before the end of the 2 minutes then resume your work prior to the sounding of the bell.

If any aspects of these instructions are unclear to you then please attract the attention of the investigator by raising your hand.

INSTRUCTIONS FOR SUBJECTS IN COMPONENTS CONDITION

In this study you are required to tackle a design problem which has been devised to be well within your range of ability and technical understanding.

You have approximately 1 hour to pursue this design and you have been provided with a variety of technical data that may be of help to you. Please attempt this problem using your preferred strategies and methods of working. You are requested to design in silence and to carry out your design work on the blank paper provided. You are reminded that while your design ideas will be assessed your anonymity is assured at all times.

Please note that this study involves a procedural manipulation that it is essential you adhere to. At 10 minute intervals throughout the study a bell will be sounded. When this occurs cease your design work, take a sheet of the specially formated paper and very briefly WRITE DOWN THE NAMES OF THE COMPONENTS THAT YOU HAVE RECENTLY INCLUDED IN YOUR DESIGN AND LIST TWO TECHNICAL ATTRIBUTES OF EACH.

For example, if you were working on a problem involving the design of a power supply system you might at some point you may have included the following components in your design:

COMPONENTS THAT I HAVE RECENTLY INCLUDED IN MY DESIGN AND TWO TECHNICAL ATTRIBUTES OF EACH

IC for control of power supply (resonant mode, 2MHz)

Bipolar transistor (500 volts, 10ns)

2 x Resistors (10k, 1/4W)

You will have 2 minutes to write down the goals relating to your design work. The end of this 2 minute period will be marked by the sound of the bell, at which point you should resume your design work. If you have completed writing down the component names and two attributes of each before the end of the 2 minutes then resume your work prior to the sounding of the bell.

If any aspects of these instructions are unclear to you then please attract the attention of the investigator by raising your hand.

C.2. ASSESSMENT OF DESIGN SCRIPTS

C.2.1. INSTRUCTIONS TO ASSESSORS

Please take a new question form for each subject and check that the subject number on the form corresponds to that on the actual design script.

Respond to each question by circling the answer which in your opinion is the most appropriate reply to the question.

Please ensure that you attempt to make a response to each of the questions asked. If you ever feel that it is impossible to make a response then leave the scale blank and briefly state why an answer cannot be made.

C.2.2. RATINGS SCALES FOR ASSESSING DESIGN QUALITY

Section 1: Quality of the subject's design process

(a) Is there any evidence that the subject attempted to gain a complete and accurate initial mental representation of the functional requirements and design constraints mentioned within the problem statement?

very much evidence	much evidence	some evidence	little evidence	very little or no evidence

(b) Is there any evidence that the subject at any time attempted to define functional requirements and constraints that were underspecified or not specified within the problem statement?

very much evidence	much evidence	some evidence	little evidence	very little or no evidence

(c) In general, did the subject generate alternative technical options (as opposed to sticking with the first technical concepts generated)?

never	seldom	sometimes	often	always

(d) In general, to what extent were alternative technical options similar or different to the original concepts generated?

substantially similar	very similar	of intermediate similarity	very dissimilar	substantially dissimilar

(e) In general, were alternative technical options actually developed further by the subject after being generated.

never	seldom	sometimes	often	always

(f) In general, did the subject engage in any structured comparison and evaluation of alternative technical concepts to assess which was the more optimal?

never	seldom	sometimes	often	always

(g) In general, was the subject consistent in his/her use of notation during the design session?

never	seldom	sometimes	often	always

(h) In general, to what extent did the subject's design activities appear to have been structured and systematic?

extremely structured	very structured	of intermediate structuredness	very unstructured	extremely unstructured

(i) Did the subject appear to make use of a 'problem reduction' strategy to tackle the overriding design problem or subsequent subproblems?

never	seldom	sometimes	often	always

(j) Is there any evidence that the subject attempted to develop design solutions to subproblems in a 'top-down' manner?

very much evidence	much evidence	some evidence	little evidence	very little or no evidence

(k) Is there any evidence that the subject attempted to develop design solutions to subproblems in a 'breadth-first' manner?

very much evidence	much evidence	some evidence	little evidence	very little or no evidence

Section 2: Quality of the subject's design solution

(l) To what extent were any functional requirements and constraints that the engineer defined during the design session sensible or sound?

extremely sound	very sound	of intermediate soundness	very unsound	extremely unsound

(m) To what extent was the subject's final design solution complete with respect to the specified functional requirements and design constraints?

extremely complete	very complete	of intermediate completeness	very incomplete	extremely incomplete

(n) Irrespective of the completeness of the subject's final design solution, how accurately did it match the specified functional requirements and design constraints?

extremely accurately	very accurately	with intermediate accuracy	very inaccurately	extremely inaccurately

(o) Irrespective of the completeness of the subject's final design solution, to what extent was it an optimal solution to the specified functional requirements and design constraints?

extremely optimal	very optimal	satisfactory	very suboptimal	extremely suboptimal

C.2.3. WRITTEN BRIEFING GIVEN TO ASSESSORS

The following written briefing was given to assessors in an attempt to ensure their consistent interpretation of the ratings questions.

DETAILS RELATING TO THE MEANING AND INTERPRETATION OF QUESTIONS

The aim of this section is to provide details relating to the meaning of the terms that you will encounter in the questions. This has been done in an attempt to ensure a high level of consistency in the way that different assessors interpret the questions.

Section 1: Quality of the subject's design process

(a) Much of the information contained within the actual statement of a design problem relates to the functional requirements of a desired artifact and the constraints that it must meet. Gaining a complete and accurate mental representation of this information is clearly an important prerequisite for design success. In the present context, evidence that the subject was attempting to gain a full representation of the problem might include, for example, any structured notes which itemised the required functionality of the sound level monitoring instrument.

(b) Design problems often arrive in an 'ill-defined' form in the sense that certain functional requirements or design constraints are either underspecified or not specified at all. For design success it is necessary for the designer to define functional requirements and constraints that are underspecified or implicit in the problem statement. This process of problem definition, though more likely to occur at the beginning of the design session, might also occur at other points.

(c) When an engineer is designing he/she will generate 'technical concepts' that form part of the solution to the design problem. These technical concepts may be understood as being 'design objects' that fulfill specified functional requirements and design constraints. These may be generated at any level of design detail and may be, for example, abstract functional blocks (eg microprocessor) or specific components and devices (eg R6500/11 Microcomputer; Transducer A). Rather than sticking with an initial technical concept that has been generated the designer may generate one or more 'alternative technical options' - indicating a search for a potentially more optimal design solution.

(d) An 'alternative technical option', if generated, might be substantially similar to the initially generated technical concept (ie only be different in terms of one or two attributes, such as its power consumption or its expense). On the other hand an 'alternative technical option' might be substantially different to the initially generated technical concept (ie be different in terms of a wide range of attributes).

(e) An 'alternative technical option' might be generated by the designer, but might be abandoned before being developed and evaluated further.

(f) Although a designer might generate and develop an 'alternative technical option' he/she might fail to fully compare and contrast this option with other previously generated options. A consequence of this could be, for example, that the designer sticks with an 'alternative technical option' that is actually less optimal than an previously generated technical option. A structured process of comparing and contrasting technical options on important dimensions (eg some form of cost/benefit analysis) would prevent such oversights.

(g) The 'notation' that a designer uses to label technical design concepts and their attributes might be inconsistent from one moment to the next which could lead to design difficulties and errors. For example, the designer might initially denote a dimension using an upper case letter "D" but might later switch to the use of a lower case letter "d".

(h) The extent to which a designer's activities are 'structured' and 'systematic' depends largely on the extent to which structured design approaches are adopted for both the generation and evaluation of technical solution concepts. Evidence of a structured approach might include (1) the use of headings and subheadings to separate design work on different parts of the overriding problem (2) the use of lines drawn across the page to segregate work relating to different aspects of a problem and (3) the use of numbering schemes to label design subproblems.

(i) A 'problem reduction' strategy is sometimes seen to be used in design situations to reduce a complex problem into a set of more manageable subproblems. Such a strategy may be used to tackle both the initial design problems and any subsequent subproblems that are produced. In application this problem reduction strategy initially leads to a division of the overriding design problem into a set of conceptually distinct (but interacting) subproblems relating to the design of separate functional modules of the desired artifact. Later on in the design process, the problem of designing a complex functional module might be subdivided into sub-subproblems relating to the design of separate sub-modules.

(j) 'Top-down' development of design solutions refers to the process of iterating solutions to subproblems through levels of increasing design detail (ie form the abstract through to the concrete). In the present context, evidence for such a process would include the generation of abstract 'solution concepts' (eg microcomputer) by the subject prior to the generation of more detailed 'solution concepts' (eg R6500/11 Microcomputer).

(k) 'Breadth-first' development of design solutions refers to the process of developing solutions to all subproblems that coexist at one level of design detail before then proceeding to iterate these solutions to the next level of design detail. Subproblems at any particular level of detail are usually seen to be tackled one at a time. This 'breadth-first' mode of expansion can be contrasted with a 'depth-first' approach where coexisting top-level subproblems are again tackled one at a time but where each subproblem is focussed on continually until a very detailed solution is attained.

Section 2: Quality of the subject's design solution

(l) As was noted in the explanation of question (b), for design success it is often necessary for the designer to define functional requirements and constraints that are underspecified or implicit in the problem statement. The definition of such information should clearly be based on the application of sensible and appropriate technical knowledge.

(m) The final solution to a design problem may be 'complete' or 'incomplete' in the way it matches the full set of functional requirements and constraints stated in the specification.

(n) Irrespective of how complete a final design solution is, what exists may be 'accurate' or 'inaccurate' in the way it matches functional requirements and design constraints detailed in the design specification. In the present context a partly inaccurate final design would be if the engineer had produced a device that was 'expensive' as opposed to the requirement for it to be 'reasonably priced'.

(o) Irrespective of how complete a final design solution is, what exists may be 'optimal' or 'suboptimal' in terms of the way it matches functional requirements and design constraints detailed in the design specification. Optimality is partly dependent on the 'accuracy' of the match between a final design solution and specified requirements and constraints. However, a final design solution might match the specified requirements and constraints 'extremely accurately' but still only be a 'satisfactory' solution. In the present context it is necessary for you - as the assessor - to rate the optimality of the final design solution in terms of your own knowledge of what an ideal solution might be.