

April 2016

Historic Computer Simulation

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IQP MBJ 1604:
HISTORIC COMPUTER SIMULATION

An Interactive Qualifying Project Report
submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Zackery Mason

April 28, 2016

Advisor:

Brian Moriarty, IMGD Professor of Practice

Abstract

GENIAC was a build-it-yourself computer kit for teens published by ACM co-founder Edmund C. Berkeley in 1955. With 6 rotatable wheels, ten light bulbs and batteries, young experimenters could wire simple circuits to demonstrate digital logic and play crude games. This report describes a project to recreate the functionality of GENIAC and its successor products using 2D web technologies, allowing a new generation of users to play all of the original circuits as well as create and share their own designs.

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1. Introduction



Figure 1. Edmund Berkeley, creator of Simon and GENIAC, the first personal computers.

Source: http://www.computerhistory.org/t dih/img/21March_2.jpg

1.1. Edmund Berkeley

Edmund C. Berkeley (1909-1988) graduated from Harvard in 1930 with a BA in Mathematics and Logic (Figure 1). He became an actuary at Prudential Insurance, quickly rising through the ranks to become Chief Research Consultant by 1934. After a short stint in the Navy during World War II, he returned to Prudential, where he was influential in securing a contract for one of the first UNIVAC computers. He also co-founded the Association for Computing Machinery (ACM) in 1947.

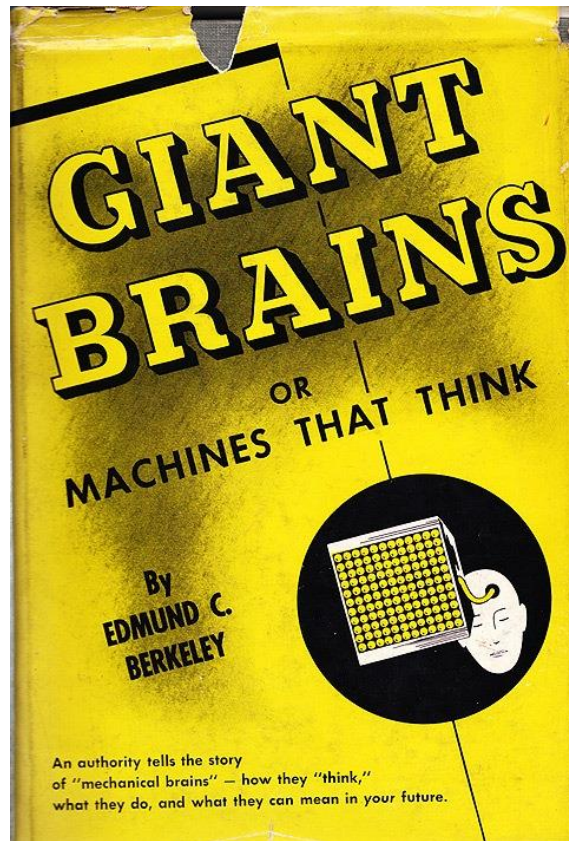


Figure 2. Berkeley's *Giant Brains, or Machines That Think* (Wiley, 1949). Source: http://timoelliott.com/blog/WindowsLiveWriter/MachinesThatThinkin1949_142F6/giant-brains,-or-machines-that-think_2.jpg

Under scrutiny for his anti-nuclear activism, Berkeley left Prudential in 1948 to become an independent consultant. His 1949 book *Giant Brains, or Machines That Think* (Figure 2) marked the beginning of a lifelong passion for explaining and popularizing computing technology. [1]



Figure 3. Simon, “world’s smallest electric brain,” on the cover of *Radio-Electronics* (October 1950). Source: http://history-computer.com/ModernComputer/Personal/images/radio-electronics_1950_Oct.jpg

1.2. Simon (1950)

Berkeley began selling plans for Simon, the first “personal” computer, in 1950. This 2-bit device contained 125 relays, used switches and paper tape for input and light bulbs for output, and required a large external power supply. It appeared as a cover article in *Scientific American* (November 1950), and was further explained over the course of fourteen articles published in *Radio Electronics* beginning in October of that year (Figure 3).



Figure 4. Fourth edition of GENIAC, December 1950.

Source: http://www.vintagecomputer.net/Geniac/Geniac_Kit_pic1.JPG

1.3. GENIAC (1955)

Simon's high complexity and construction cost (\$600, equivalent to nearly \$6,000 in 2016) prompted Berkeley to seek a less expensive means of introducing computers to consumers. He achieved this goal in Spring of 1955 with the release of GENIAC (GENIus Automatic Computer), a \$17.95 kit of electrical parts that could be configured to demonstrate simple computing tasks, such as binary adders, multipliers and comparators, together with a variety of gadgets, such as an intelligence tester and a combination lock (Figure 4). Two of the thirty-three projects described in the original GENIAC manual, "The Machine to Play Nim" (Project 26) and "The Machine to Play Tick-Tack-Toe" (Project 27), are the first computer games ever offered to home consumers. [2]

For Problem-Solving . . . Experimentation . . . Teaching . . . or Just Fun

BUILD YOUR OWN ELECTRIC BRAIN MACHINE

IN JUST A FEW HOURS!

Remarkable 400-Component Construction Kit Enables You to Create Any of 33 Brain Machines! Build **LOGIC MACHINES** That Compare, Reason, Test Intelligence; **ARITHMETICAL MACHINES** (Binary & Decimal); **GAME-PLAYING MACHINES** (Tic-Tac-Toe, Nim, etc.)

Teachers and Scientists: Design Your Own Machines!

GENIAC is the only kit and text combination that presents the basic ideas of cybernetics, boolean algebra, symbolic logic and computer circuitry for all levels of knowledge and intelligence. Sold to all customers on a one-week return guarantee; actually use it during that time, return it if you decide not to keep it.

WITH GENIAC you build any of 33 electric brain machines in a few hours by following the clear-cut, step-by-step directions in the basic text provided. Advanced students and scientists can design machines for special problems. No soldering required, and little wiring. Change design of your machines in minutes! Build Binary Adding Machine • Secret Coder & Decoder • Machine for Arithmetical Carrying • Comparing Machine • Reasoning Machine • General Combination Locks • Games Requiring Logic • Machine for a Space Ship's Ailock • Intelligence Tester • Burglar Alarm • Puzzle Solvers and many others.

OVER 400 COMPONENTS AND PARTS

Circuits operate on one flashlight battery, and use ingeniously designed parts. 1957 GENIAC Kit has been constructed by the original inventor to provide all the advantages of previous electrical brain construction kits plus what we have learned in answering the questions and examining the new designs created by hundreds of users.

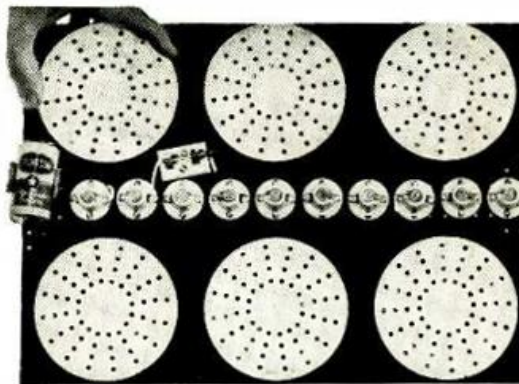
SELF-CONTAINED COURSE IN COMPUTER DESIGN

Each GENIAC comes as a self-contained course in computer design. All instructions are so simple that we have records of intelligent twelve-year-olds designing factoring machines and puzzle-solving circuits—while hundreds of schools and industrial training programs have incorporated our kits in their curricula.

YOUR COURSE FOR GENIAC KIT: ONLY \$19.95 POSTPAID

The coupon will bring your GENIAC Electric Brain Construction Kit and Manuals for only \$19.95 postpaid. You may return the Kit within 7 days if you are not completely satisfied. For schools we offer bulk rates on extra texts and parts; for teachers, we offer 10% deduction on GENIAC if ordered for use in institutions. Send for your Kit today!

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1957 GENIAC KIT CONTAINS (1) a complete 200-page text "Minds and Machines"—a basic introduction to computers; (2) "How to Construct Electrical Brains at Home"—a fully illustrated text book on basic computer design theory and circuits with specific instructions for building 33 circuits; (3) Wiring Diagram Manual. A special booklet with full scale diagrams; (4) Beginners' Manual—fifteen extra experiments to teach the basic symbols of electric circuits; (5) Over 400 components and parts.

Some Institutions and Firms Now Using GENIAC

- | | | |
|------------------------|---------------------|-------------------------|
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| Remington-Rand | Rohr Aircraft Co. | Schools |
| International Business | Southwest Missouri | Jefferson Union High |
| Machines | State College | School |
| Whitoides Mfg. Co. | Albert Einstein | Oklahoma A & M |
| Wagoner Missionary | Medical College | Kansas State University |
| College | Naval Research | Duke University |
| Walter V. Clarke | Laboratories | Corral Gables Senior |
| Associates | Board of Education, | High School |
| Barvard College | Tecumseh, Nebraska | Courland Jr. High |
| Westinghouse Electric | Marchfield Public | School |
| Phillips Laboratories | School | Bell Telephone |
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ORDER GENIAC ON OUR MONEY BACK Guarantee!

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Please send me:
 1 GENIAC Electric Brain Construction Kit and Manuals
 \$19.95 (Base of Mississippi)
 \$20.95 (elsewhere in United States)
 \$21.95 (outside the United States)
 Returnable in seven days, for full refund if not satisfied. I enclose \$..... in full payment.

Name.....
 Address.....
 City..... Zone..... State.....

Figure 5. Advertisement for GENIAC from *Radio-Electronics* (May 1957, p. 23).



Figure 6. Cover and interior of BRAINIAC, the 1957 update of GENIAC.

Source: <http://ludix.com/moriarty/electric.html>

Marketed to teenaged hobbyists through magazines like *Radio-Electronics* and *Boy's Life* (Figure 5), GENIAC went through several iterations and re-brandings, including two cost-reduced versions, TINIAC and WEENIAC, in 1957. Berkeley's introduction of BRAINIAC in 1957 constituted a major upgrade of the original GENIAC, with improved manuals, extra parts, more projects to build and attractive packaging (Figure 6).

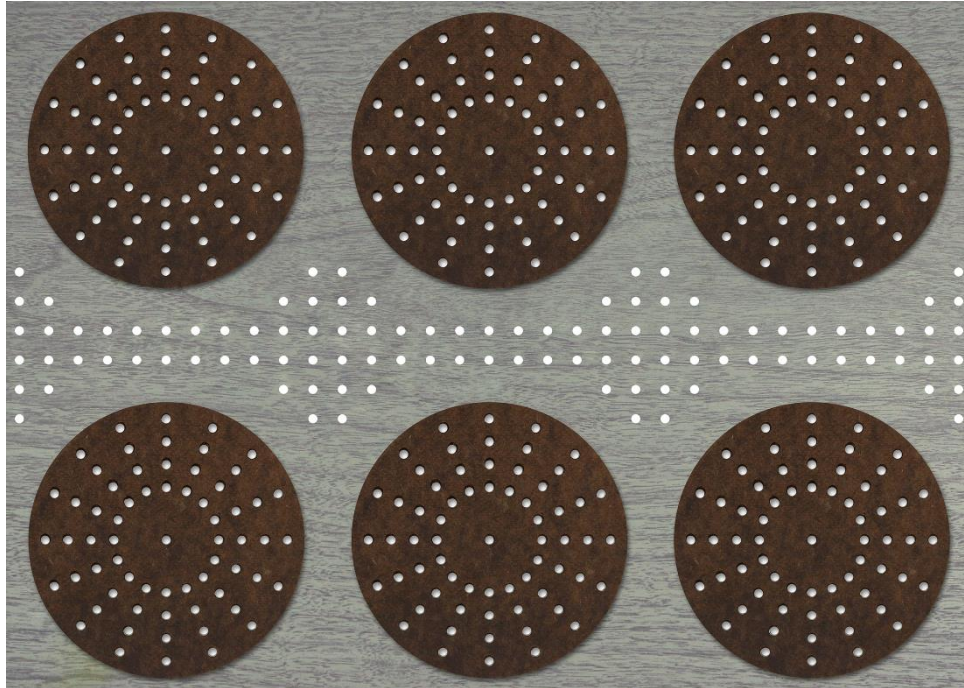


Figure 7. GENIAC project board and dials, before wiring.

Source: <http://ludix.com/moriarty/electric.html>

2. Design of GENIAC

GENIAC is an electric state machine, “programmed” by hardwiring its electric components into different circuit configurations (Figure 7). Moriarty describes the device succinctly:

The base components are a perforated Masonite project board and six large dials with matching holes. By attaching conductive bolts and jumpers to these components, custom rotary switches can be assembled. Each switch supports up to 16 positions, with one or two poles per position.

Incandescent light bulbs, powered by a pair of D batteries, are used to indicate the state of the circuit. Logic is implemented by wiring the switch poles together.

The jumpers on the dials are aligned to match the poles on the project board. A power switch between the batteries activates the circuit. Different bulbs are illuminated as each dial is turned, depending on the logic instantiated by the wiring. [2]

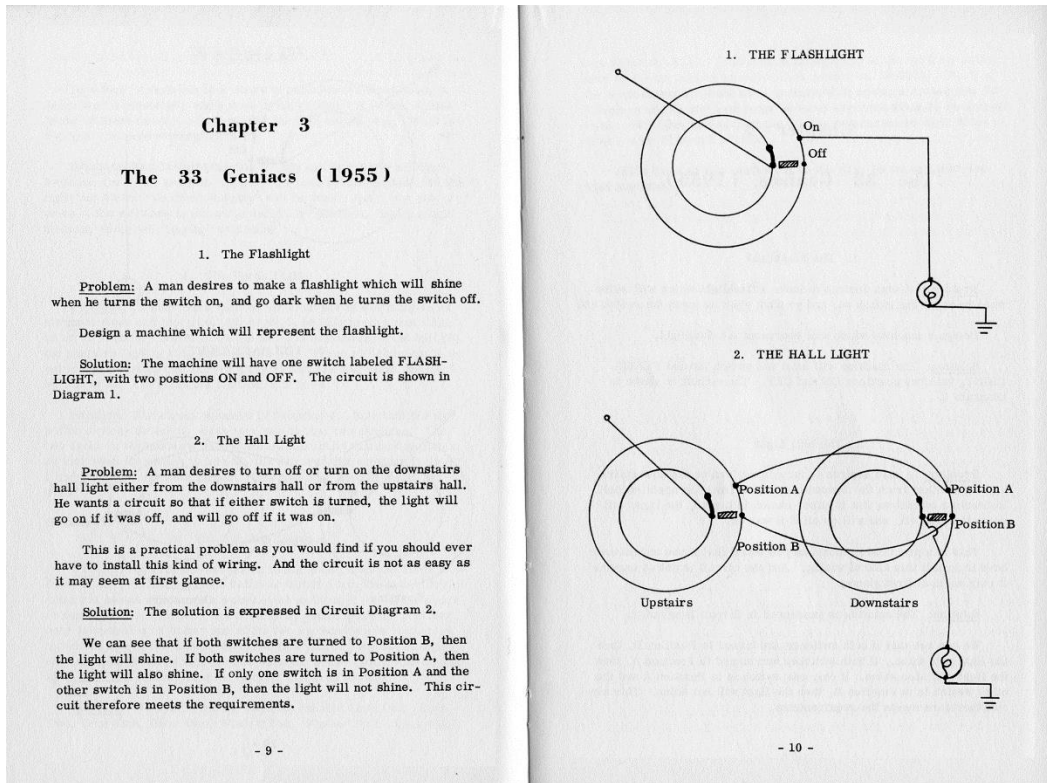


Figure 8. Descriptions and circuit diagrams for two simple GENIAC projects. [3]

Once mounted to the project board on spindles, the dials are free to turn in place. All wiring takes place on the back of the board. Electrical contact points or “nodes” are established by installing screws and nuts at desired positions under the dials, then connected by attaching wires between them. Jumpers installed on the underside on the dials determine how nodes are connected as the dials are rotated to different positions (Figure 8).

The output states of a project are indicated by 3V miniature incandescent bulbs. Sockets for up to ten bulbs are provided, along with holders for two D batteries and a master power switch. User-provided labels are usually positioned beside the wheels and lamps to facilitate interpretation of the circuit.

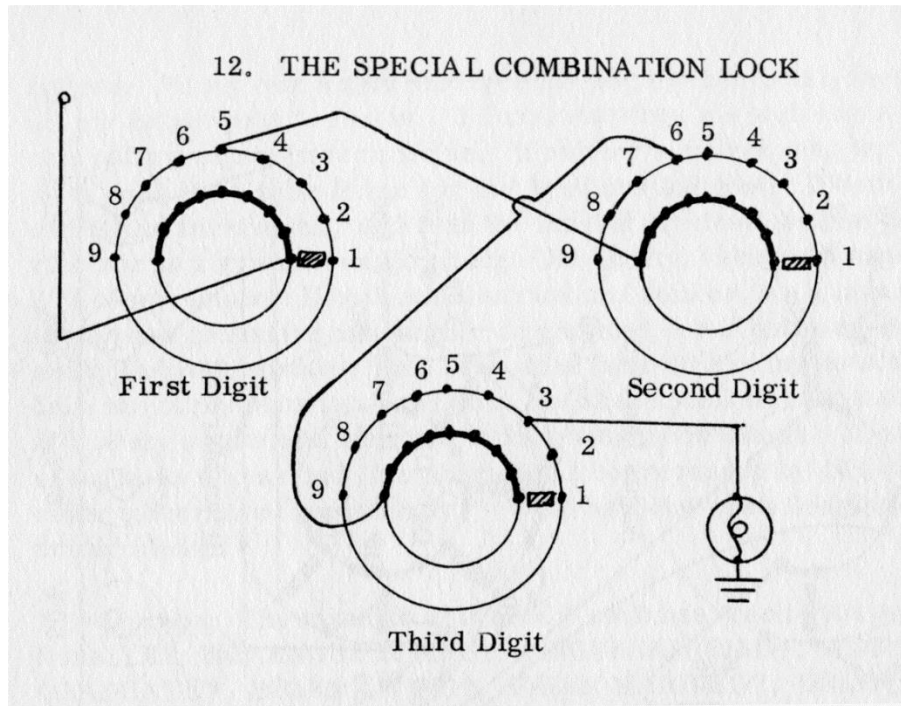


Figure 9. Circuit diagram for GENIAC Project 12, “The Special Combination Lock.” [3]

Project 12 from the GENIAC manual, “The Special Combination Lock,” is a typical example (Figure 9). The circuit simulates an electrical lock with three digits (0-9). The “open” lamp illuminates only if the dials are set to a hardwired sequence, in this case 5-6-3. The batteries provide power to all ten positions of the first dial, but only the 5th pole is connected to the second dial. The second and third dials work the same, wired via their 6th and 3rd poles to the bulb.

3. Project genesis

The idea of creating a digital simulation of GENIAC began with a lecture delivered by WPI Professor of Practice Brian Moriarty at New York University's Practice 2015 Conference on 15 November 2015. His presentation, *I Sing the Story Electric*, traced the history of interactive storytelling from its roots in Elizabethan court drama to contemporary digital media. At the climax of the lecture, Moriarty recounted an accidental discovery made while touring WPI colleague Dr. George Phillip's collection of board games:

As we were preparing to leave, I suddenly noticed a familiar but quite unexpected title high on a shelf filled with miscellaneous artifacts. I turned to George in surprise.

“You have a BRAINIAC!” I said.

“Got it for my eleventh birthday,” he told me.

Very carefully, I lowered the near-mythical cardboard box from the shelf and opened the lid.

Impossible. A complete, untouched specimen!

Literally trembling with astonishment, I picked up the pristine owner's manual, and — quite randomly — opened it to page 49. [2]

The project Moriarty discovered on page 49 of the BRAINIAC manual was originally presented as GENIAC Project 23, “The Uranium Shipment and the Space Pirates,” described as follows:

Problem: A uranium shipment from one of Jupiter’s moons, Calisto, to Earth consists of a freighter rocket ship loaded with uranium and a fighter escort rocket ship disguised as a freighter. Space pirates are known to be lurking on one of the two asteroids, Pallas or Hermes. The pirates suspect that one of the rocket ships is a disguised freighter; therefore they may either attack the first ship or wait in hiding for the second ship. The commander of the uranium shipment can send either ship by the Pallas or Hermes route and can send the fighter either first or second. If the pirate attacks the fighter, the pirate will be destroyed. If the pirate attacks the uranium ship and the fighter as already passed or has taken the other route, then the pirate captures the uranium. If the pirate attacks the uranium ship, and the fighter is taking the same route, and is behind the uranium ship, the pirate is destroyed but during the battle, the pirate destroys the uranium ship. Of course, if the pirates do not attack, there is no combat. [3]

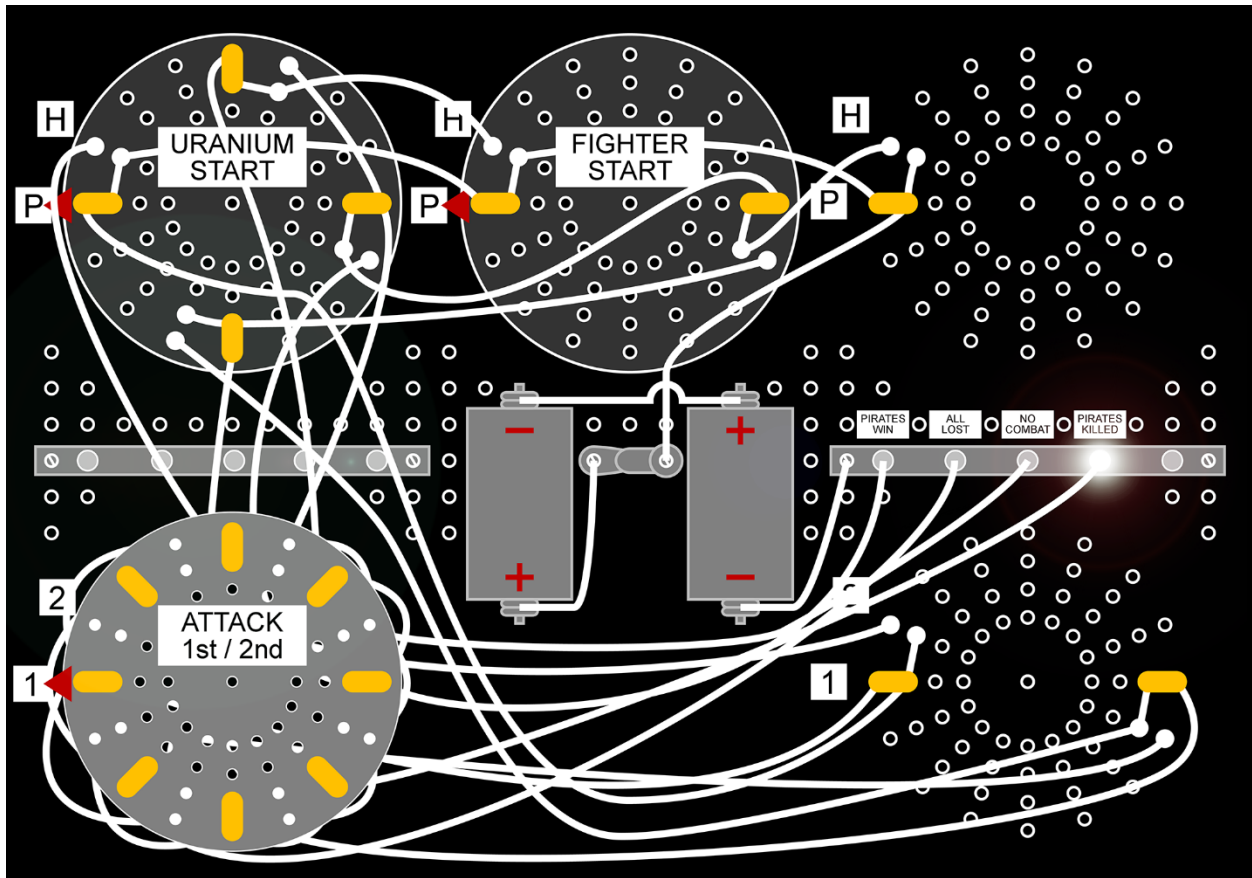


Figure 10. Wiring diagram of “The Uranium Shipment and the Space Pirates,” with the first and fourth dials removed, and the second and third dials displayed transparently.

Studying the accompanying wiring diagram (Figure 10), Moriarty recognized “The Uranium Shipment” as an early, all-but-forgotten example of computerized interactive fiction, predating the seminal works of Peter Langston, Willie Crowther and Don Woods by twenty years. He obtained permission from Dr. Phillis to assemble the project using his original BRAINIAC kit (Figure 11), and showed a video of the historic circuit in operation at the conclusion of his Practice 2015 lecture.

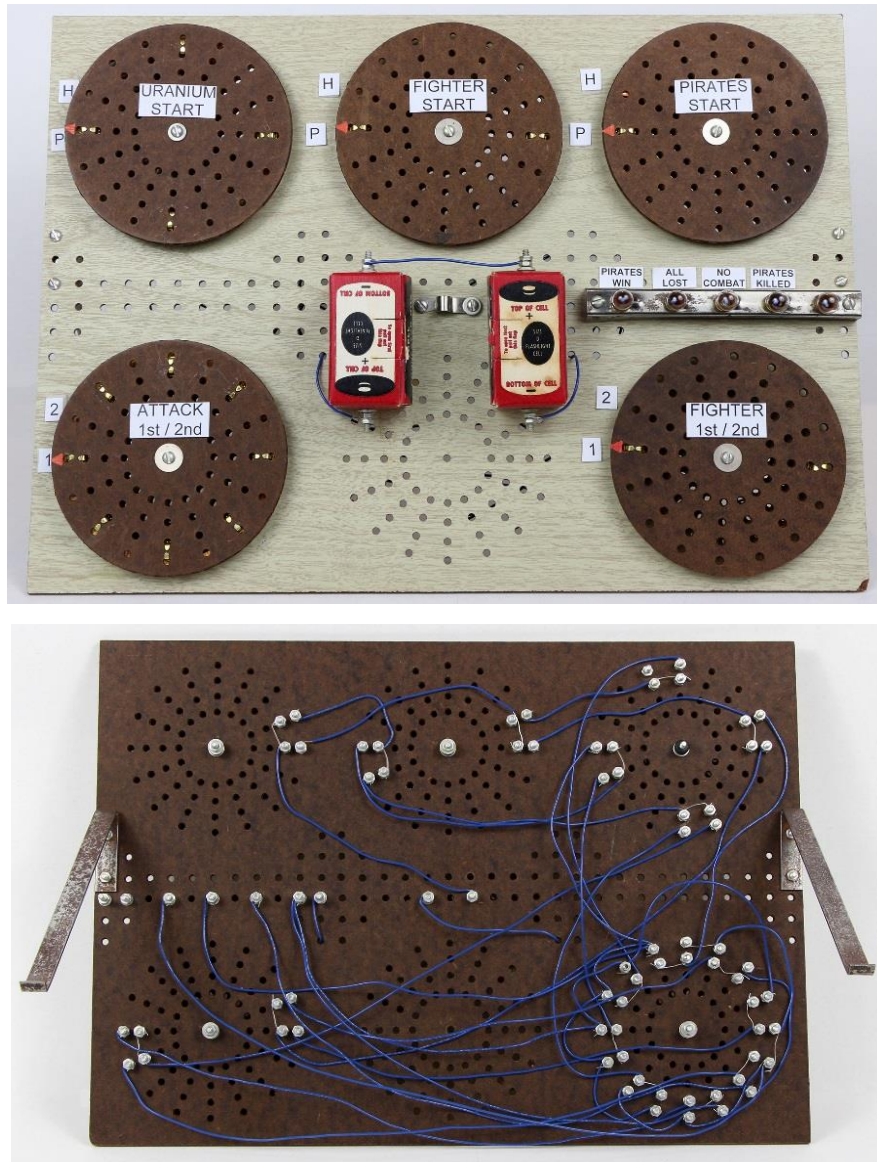


Figure 11. Front and back wiring of reconstructed GENIAC Project 23, “The Uranium Shipment and the Space Pirates.”

Source: <http://ludix.com/moriarty/electric.html>

The process of building the “Uranium Mine” project proved arduous. The aged, corroded parts made electrical contact intermittent, resulting in a flaky, unreliable device. This IQP resulted from a desire to recreate the GENIAC experience in a digital simulation that would allow the original projects to be

studied easily, and also to allow new circuits to be designed and shared by experimenters.

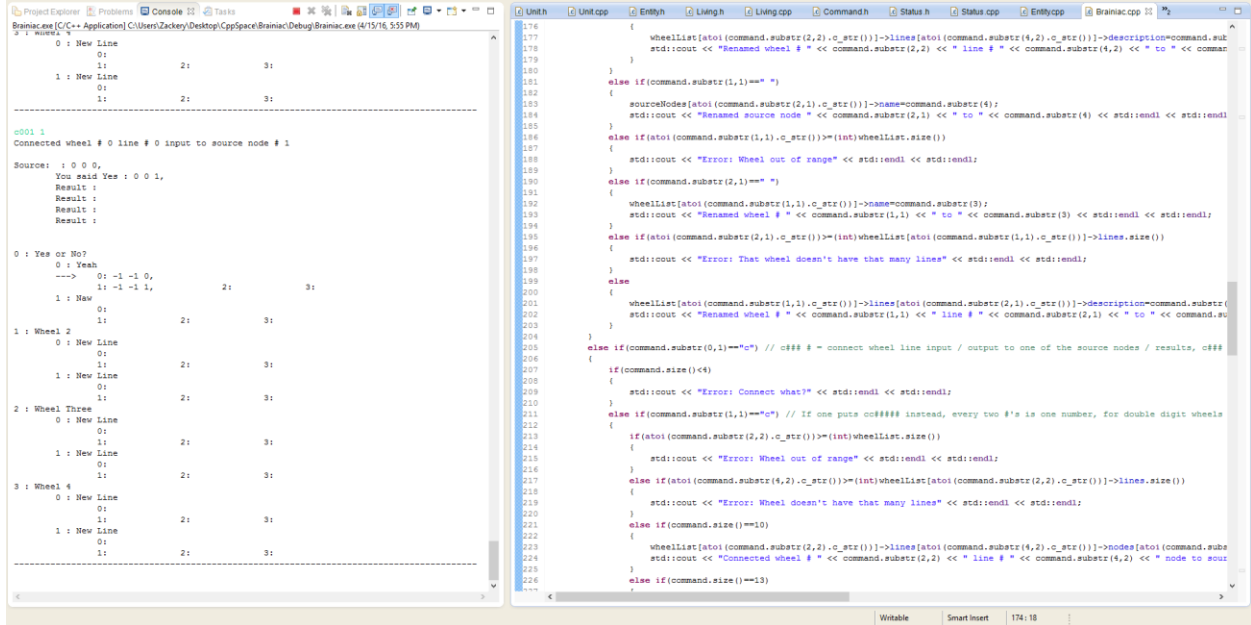


Figure 12. Sample C++ code and output of GENIAC prototype.

3.1. First prototype

The first step in the creation of the project was to create a circuit simulation that could mimic the functionality of a GENIAC. A text-based prototype was created in C++ (using the Eclipse IDE) to aid in understanding the circuitry to be simulated (Figure 12). Wheels, lines and nodes were given separate classes, using mutual pointers to establish connections.

A virtual “dial” is instantiated with an array of sixteen lines, each containing a sub-array of four nodes. Starting with six blank dials, a user can initiate several actions, such as connecting or severing two specific nodes; adding, removing or renaming nodes, lines and/or wheels, and “turning” any dial to a specific position to observe the behavior of the circuit. The state of a construction project was output in text form after every command.

Inputting the connections by hand was very tedious, and the output was difficult to comprehend easily. But eventually the prototype was able to accurately model not only the functionality of all of the original GENIAC/BRAINIAC projects, but also new projects involving an arbitrary number of dials and lamps.

The text-based prototype was a successful proof-of-concept, but its arcane interface was not suited for casual use. We clearly needed a graphical interface that looked and operated more like an actual GENIAC. Two design choices presented themselves: a realistic 3D model of the project board that users could rotate to set up the wiring in an authentic fashion, or a simpler 2D representation showing either the back of the board for wiring, or the front for turning the dials.

Because we wanted our virtual GENIAC to run in web browser, we decided on the 2D approach, to be developed using HTML5, CSS and JavaScript, augmented with the PIXI.js graphics library for improved performance and cross-browser compatibility.

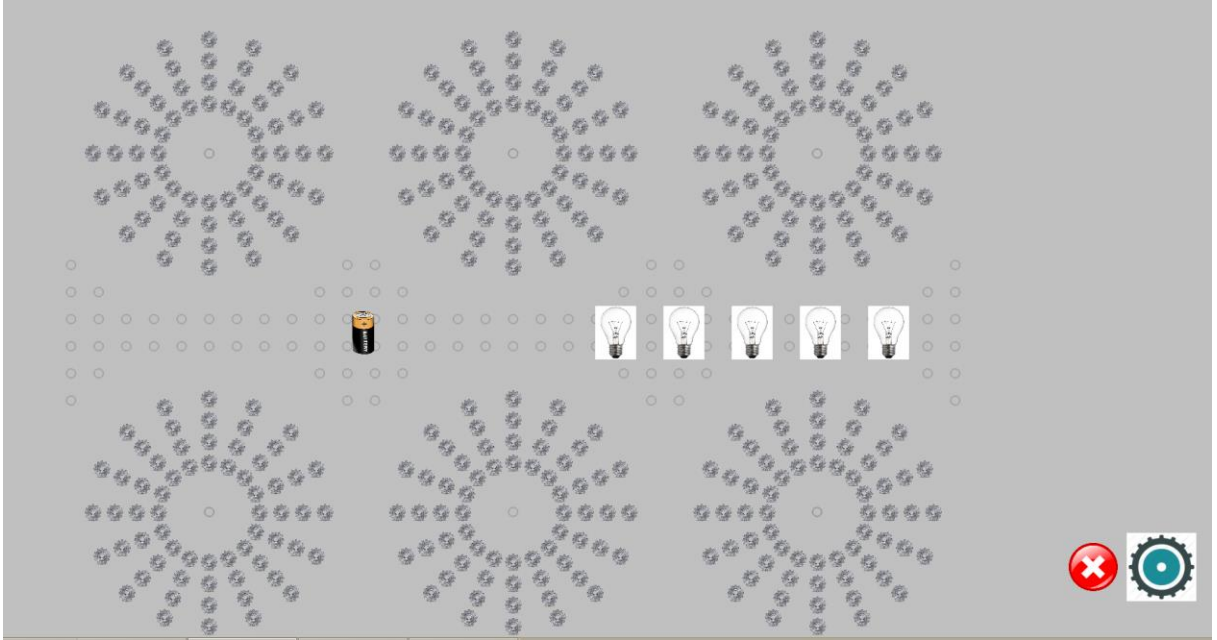


Figure 13. First-pass version of visual prototype.

3.2. Visual prototype

The first pass of our HTML5 engine only handled the wiring functionality built into the text prototype, using placeholder images (Figure 13). Nearly all of the code was rewritten from scratch, with class functionality stored in PIXI sprite objects.

Users could manually connect nodes together with clicks, turning on a lamp if a complete circuit was made from the battery. For ease of use, a “remove” button was added to clear the board faster. An “add wheel” button beside it allowed users to spawn a new dial to the right of the board, with no limit on the total number of dials.

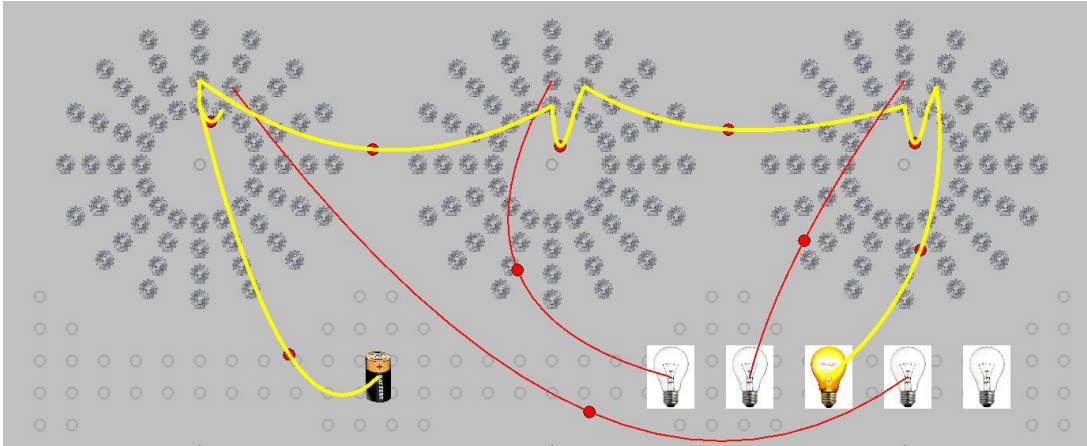


Figure 14. Example of a partially wired board.

Wires, lights and nodes with a direct path to the battery are visually distinct, and update automatically as the circuit is modified. Wires are given an initial realistic curve when created, and can be moved around to display the board better by grabbing and dragging red handles at their centers (Figure 14).

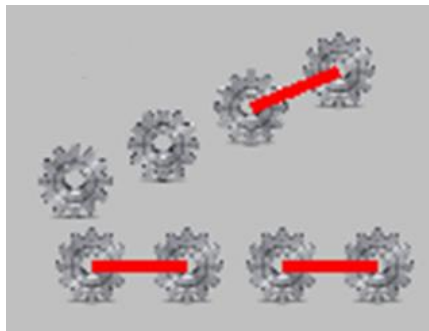


Figure 15. Adjacent nodes in a line.

At first, we were chiefly concerned in being able to wire up the projects in a way similar to the prototype, so we decided on keeping the node sprites visible at all times for easy connections, as if one was always facing the back of the project board. For authenticity, we retained GENIAC's limitation that a single node on a line cannot have two jumpers attached at the same time (Figure 15).

Nodes are connected or severed by clicking on them in succession. Dials and/or wheels are added or removed with dedicated toggle buttons on the side. Saving and loading projects were done by adding a console bar at the bottom of the screen, from which the user could save his project by copying the string that was generated after pressing the save button, or load a project by pasting the save-code in the console and pressing the load button.

3.3. Modes

With essential functionality in place, we progressed to working on the aesthetics. The first step was to allow the user to switch from wiring a project to actually playing with it. This resulted in a user interface design incorporating three modes: Wiring, Dials and Play.

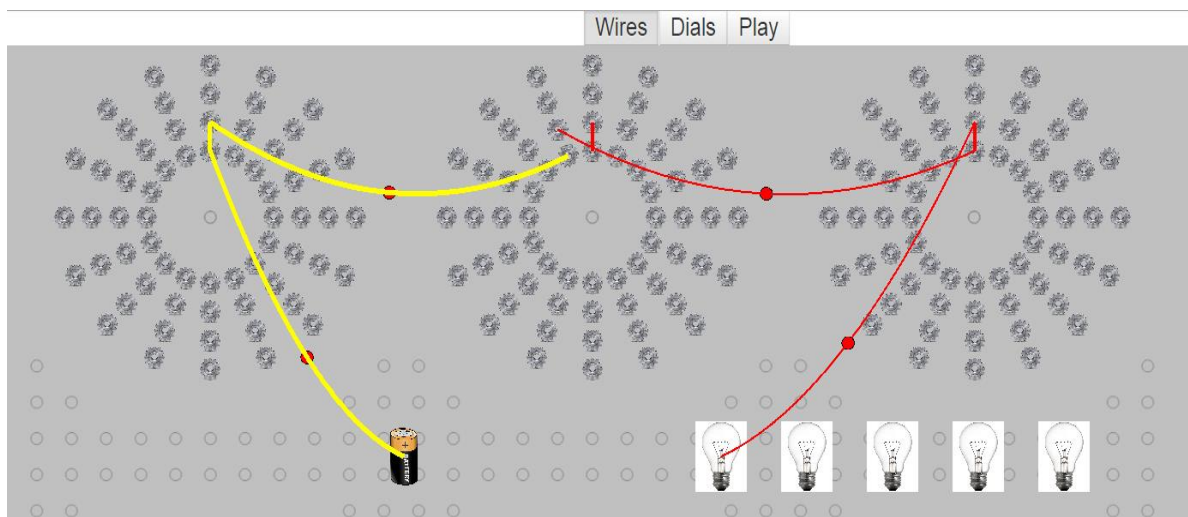


Figure 16. Early iteration of Wiring mode.

Wiring mode was exactly what we had before, a setup for letting the user connect and sever node connections to assemble the desired circuit (Figure 16).

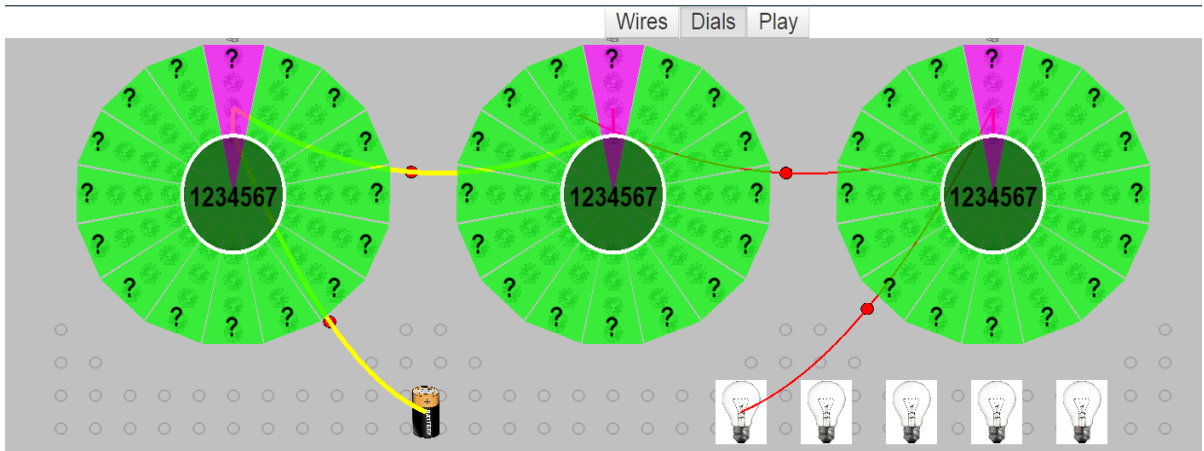


Figure 17. Early iteration of Dials mode.

Dials mode enabled the user to textually label each line of the dials, the dials themselves, and the output lamps (Figure 17). A master label provides space for describing the context of a project.

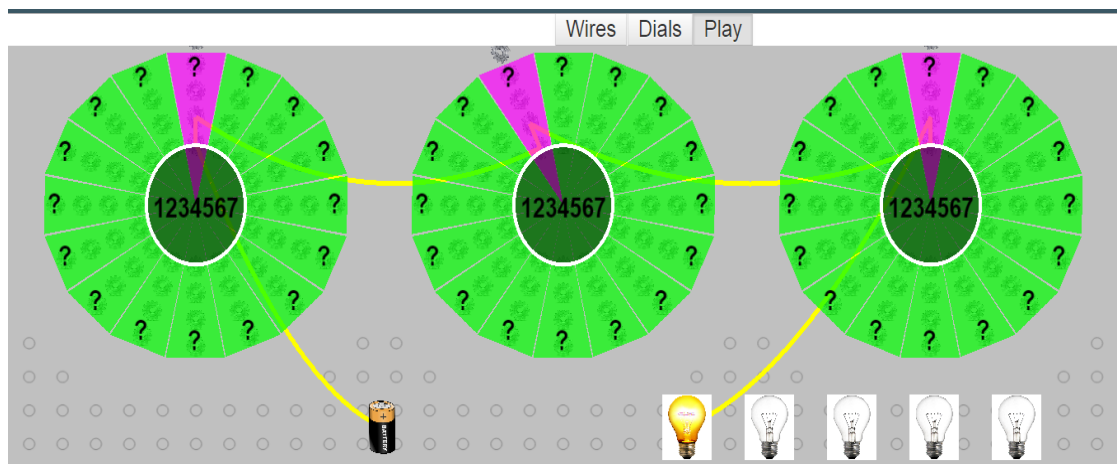


Figure 18. Early iteration of Play mode.

Play mode is used for operating finished projects, complete with rotatable dials that correctly simulate the opening and closing of circuits (Figure 18). Final iterations of Dials and Play mode are illustrated in Appendix 1.

Further design choices revolved around how different we wanted our virtual GENIAC to be from a real GENIAC, as we weren't bound by the physical limitations of the original kit. We wanted the layout to look like the front of a GENIAC, but we also wanted the text for each label to be easily legible and editable. This resulted in minor cosmetic adjustments that would not be possible with a real GENIAC, but worked fine in our simulation.



Figure 19. Example of “turning” a dial (middle top) to change the circuit state.

In the current design, “turning” a dial doesn’t visually rotate the dial around its axis. Instead, it adjusts all node connections in a clockwise direction to match the positions the dial jumpers would have spanned (Figure 19). Actually rotating the wheel was possible, but our placement of the text boxes and labels presented a conflict with such movement.

The real GENIAC project board provided space for only six dials, and most projects only used a maximum of five. There was no reason for our simulated GENIAC to share this limitation. However, adding more than six dials would require us to add some sort of camera movement around the expanded board. We wanted to allow users to go beyond the six-dial limit if they had a megaproject, so we settled on a four-board mode that could be toggled to provide three additional six-dial project boards with a moveable camera.

Conclusion

As it stands, the Virtual GENIAC project has fulfilled its intended purpose and more. The core functionality we wanted is in place. Users can modify projects and save or load their work. Individual projects can be preloaded and embedded in a web page.

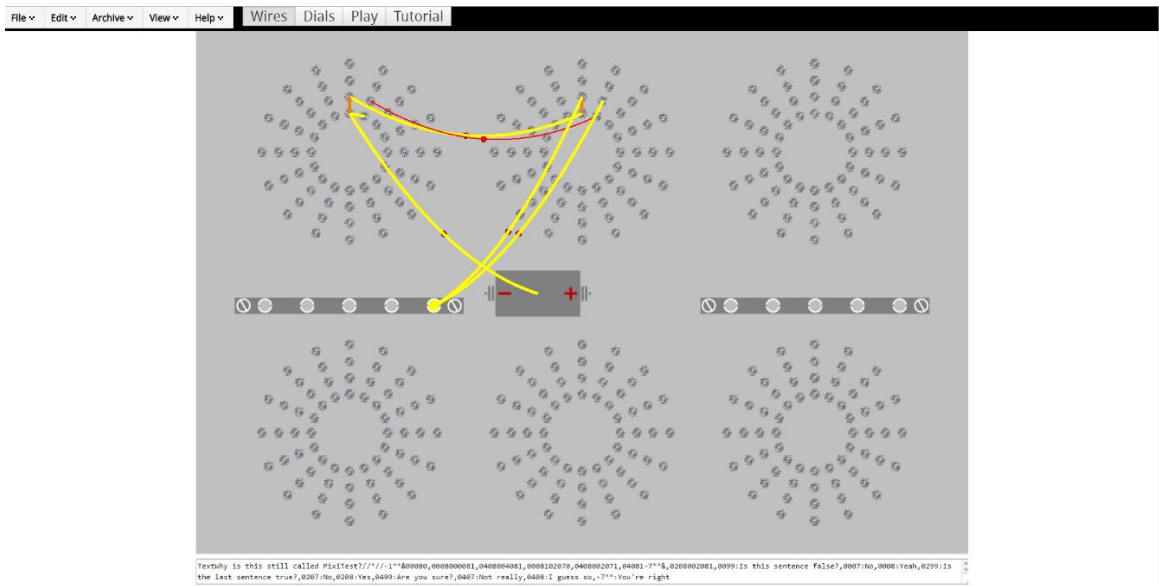
Nothing went particularly wrong in development, though certain limitations of PIXI.js stopped us from adding even more photorealistic images for wires and other details near the end.

Future development might include an online database and website where users can post and share projects, including improvements of the original GENIAC projects or completely new designs that extend beyond the limits of Berkeley’s groundbreaking project kit.

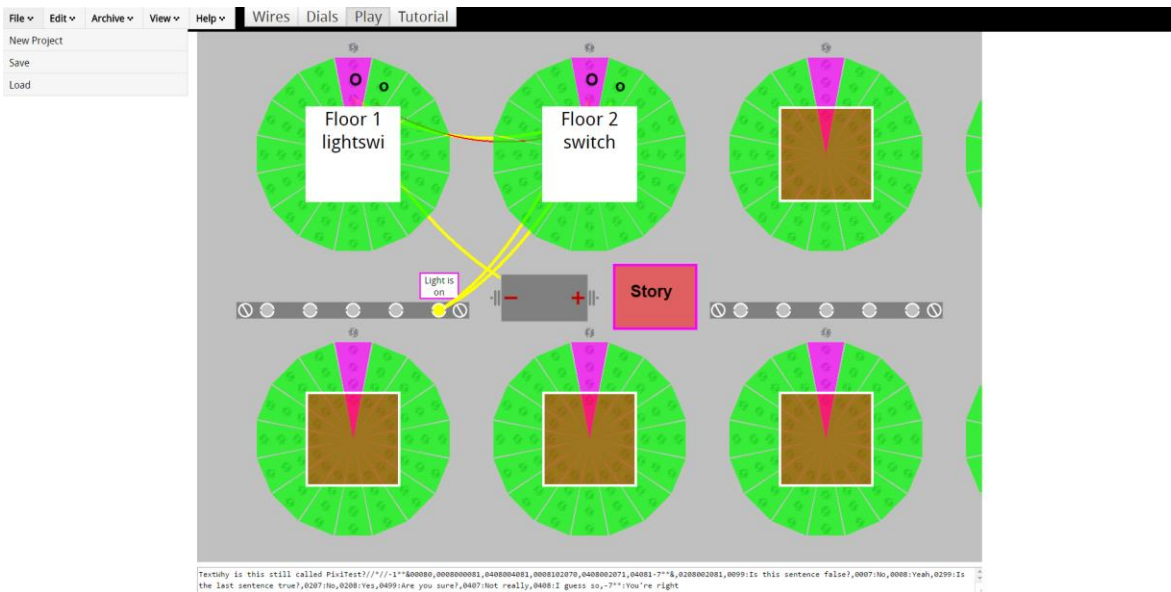
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1. Berkeley, Edmund C. *Giant Brains, or Machines that Think*. Wiley, 1949. Print.
2. Moriarty, Brian. *I Sing the Story Electric*. Web. URL: <http://www.ludix.com/moriarty/electric.html>. Retrieved 28 April 2016.
3. Berkeley, Edmund. *BRAINIACS: 201 Small Electric Brain Machines, and How To Make Them*. Berkeley Enterprises, 1961. Print.

Appendix 1: Final UI iterations



Final iteration of Wiring mode.



Final iteration of Play mode.