A Model-Based Design Tool for Systems-Level Spacecraft Design

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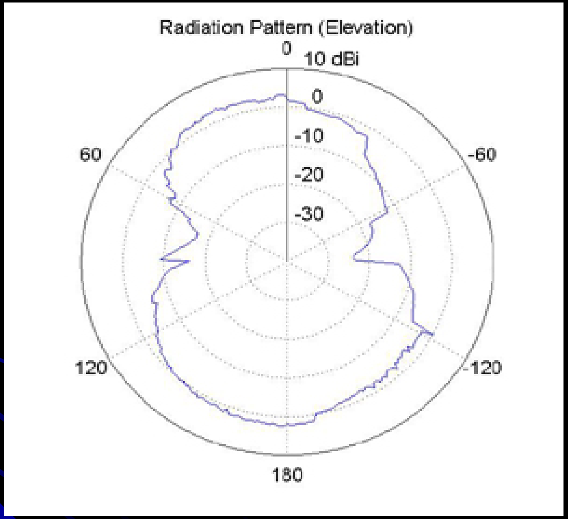
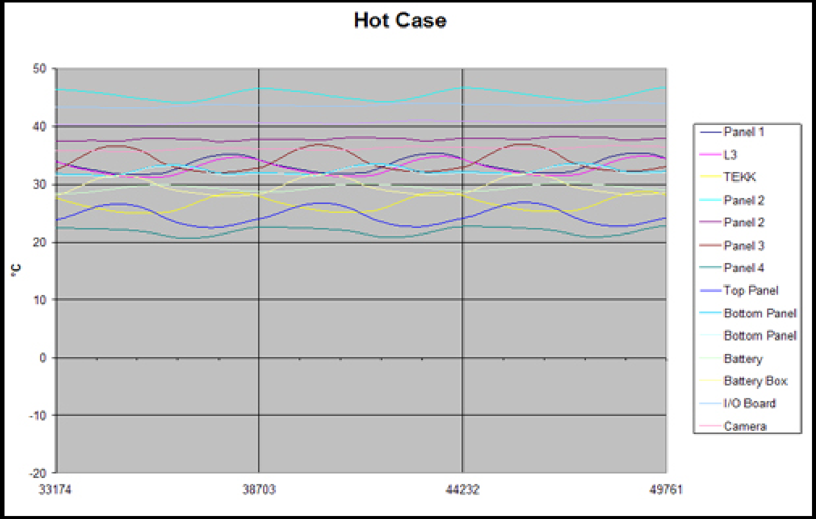
Overview

- Motivation
- Modeling Formalism
- Tool Infrastructure
- Tool Overview

Motivation

- At the subsystem level designs are mathematically modeled and analyzed to ensure that they are correct





- Spacecraft system-level behavior is typically described in prose and diagrams
  - Provides for documentation but not analysis

Goal

- Enable capture of system-level behavior models that can be rigorously analyzed to detect errors earlier in the development cycle

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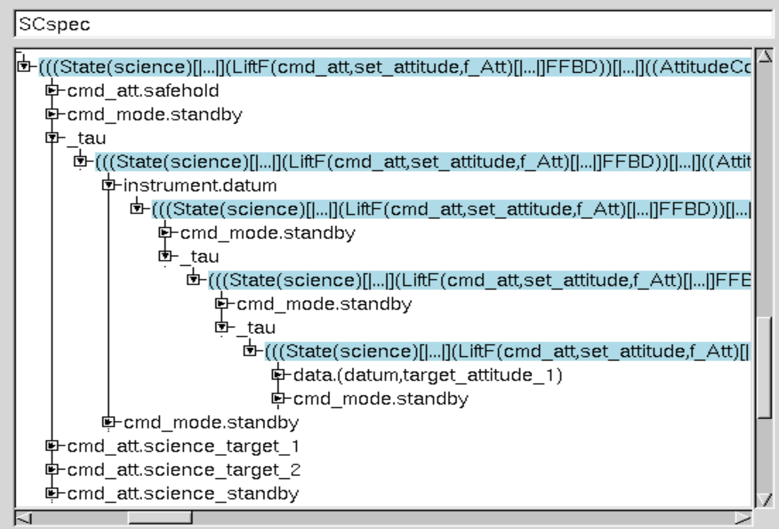
CSP

- Communicating Sequential Processes
  - Mathematical formalism originally developed for modeling interacting software components
  - History of industrial use (Daimler, Qinetiq, INMOS)
- Model behavior as processes composed of events

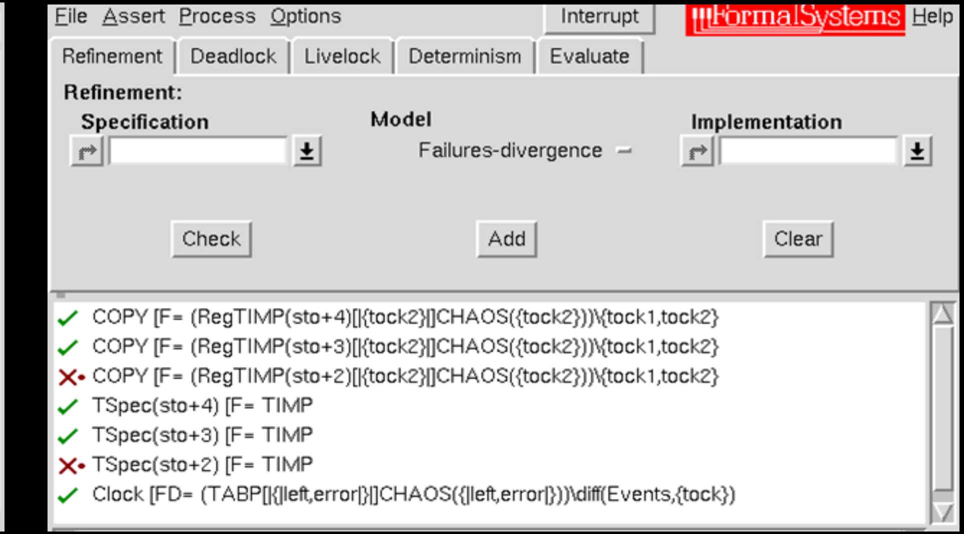
```
datatype T = t1 | t2 | t3

channel tuple: (T, T)
channel inx, iny, outx, outy: T

MergeXY =
  let
    Xin = inx?x -> [] y:T @ tuple.(x,y) -> Xin
    Yin = iny?y -> [] x:T @ tuple.(x,y) -> Yin
  within
    Xin [|{|tuple|}|] Yin
```

Using CSP

- Tool support for CSP models allows
  - Manual exploration to improve understanding of system behavior
  - Exhaustive analysis to verify that modeled behavior is correct



```
SCspec
(((State(science)[|...|](LiftF(cmd_att,set_attitude,f_Att)[|...|]FFBD))[|...|]((AttitudeCc
  cmd_att.safehold
  cmd_mode.standby
  _tau
    (((State(science)[|...|](LiftF(cmd_att,set_attitude,f_Att)[|...|]FFBD))[|...|]((Attit
      instrument.datum
        (((State(science)[|...|](LiftF(cmd_att,set_attitude,f_Att)[|...|]FFBD))[|...|
          cmd_mode.standby
          _tau
            (((State(science)[|...|](LiftF(cmd_att,set_attitude,f_Att)[|...|]FFE
              cmd_mode.standby
              _tau
                (((State(science)[|...|](LiftF(cmd_att,set_attitude,f_Att)[|
                  data.(datum,target_attitude_1)
                  cmd_mode.standby
      cmd_mode.standby
  cmd_att.science_target_1
  cmd_att.science_target_2
  cmd_att.science_standby
```



```
✓ COPY [F= (RegTIMP(sto+4)[|{tock2}|]CHAOS({tock2}))\{tock1,tock2}
✓ COPY [F= (RegTIMP(sto+3)[|{tock2}|]CHAOS({tock2}))\{tock1,tock2}
✗• COPY [F= (RegTIMP(sto+2)[|{tock2}|]CHAOS({tock2}))\{tock1,tock2}
✓ TSpec(sto+4) [F= TIMP
✓ TSpec(sto+3) [F= TIMP
✗• TSpec(sto+2) [F= TIMP
✓ Clock [FD= (TABP[|{|left,error|}|]CHAOS({|left,error|}))\diff(Events,{tock})
```

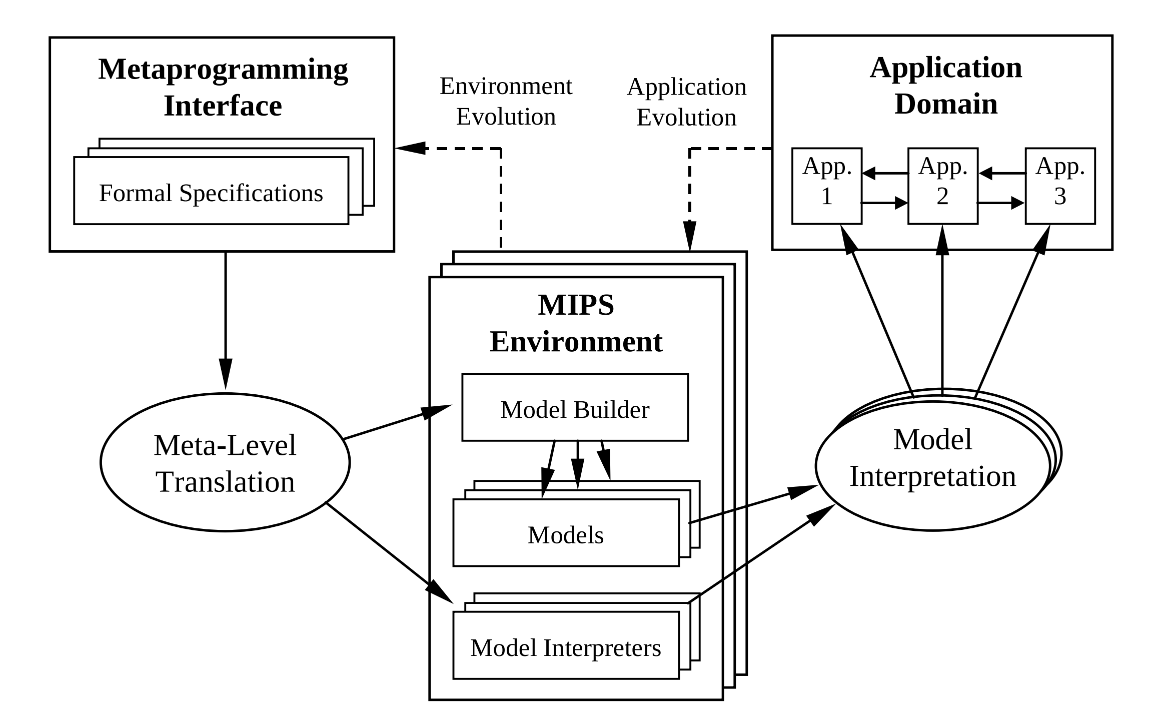
- Model-builders must understand CSP language/theory

Approach

- Develop a visual tool that supports system-level behavior modeling, and maps diagrams to CSP models

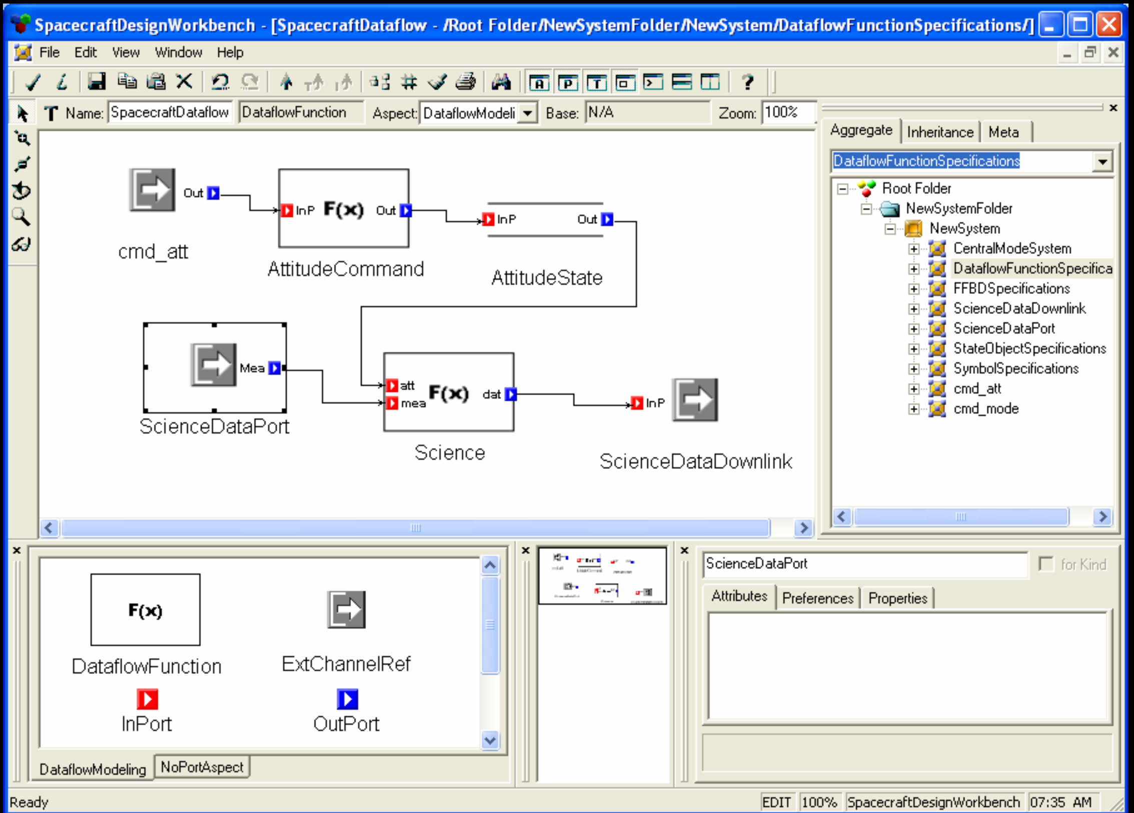
The Generic Modeling Environment

- Tool Infrastructure for implementing Domain-Specific Modeling Languages (DSMLs)
- High-level interfaces for interpreter creation: “compiler” for the visual language
  - Translate the captured diagrams into “something useful”



Spacecraft Design Workbench

- Modeling language supports three classes of diagrams:
  - Mode Transition Diagrams, FFBDs, Dataflow Diagrams
- Allows the capture of distinct views of system
- Rules and constraints govern interaction between views
- Defined mapping between diagram elements and CSP constructs



SpacecraftDesignWorkbench - [SpacecraftDataflow - /Root Folder/NewSystemFolder/NewSystem/DataflowFunctionSpecifications/]

Name: SpacecraftDataflow DataflowFunction Aspect: DataflowModeli Base: N/A Zoom: 100%

DataflowFunctionSpecifications

ScienceDataPort

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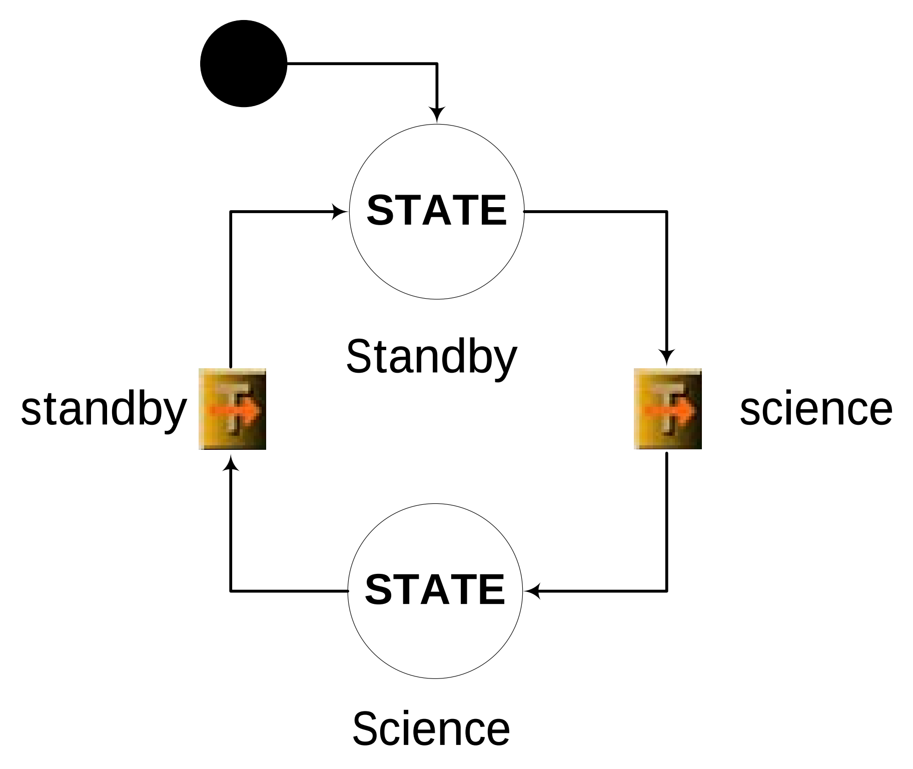
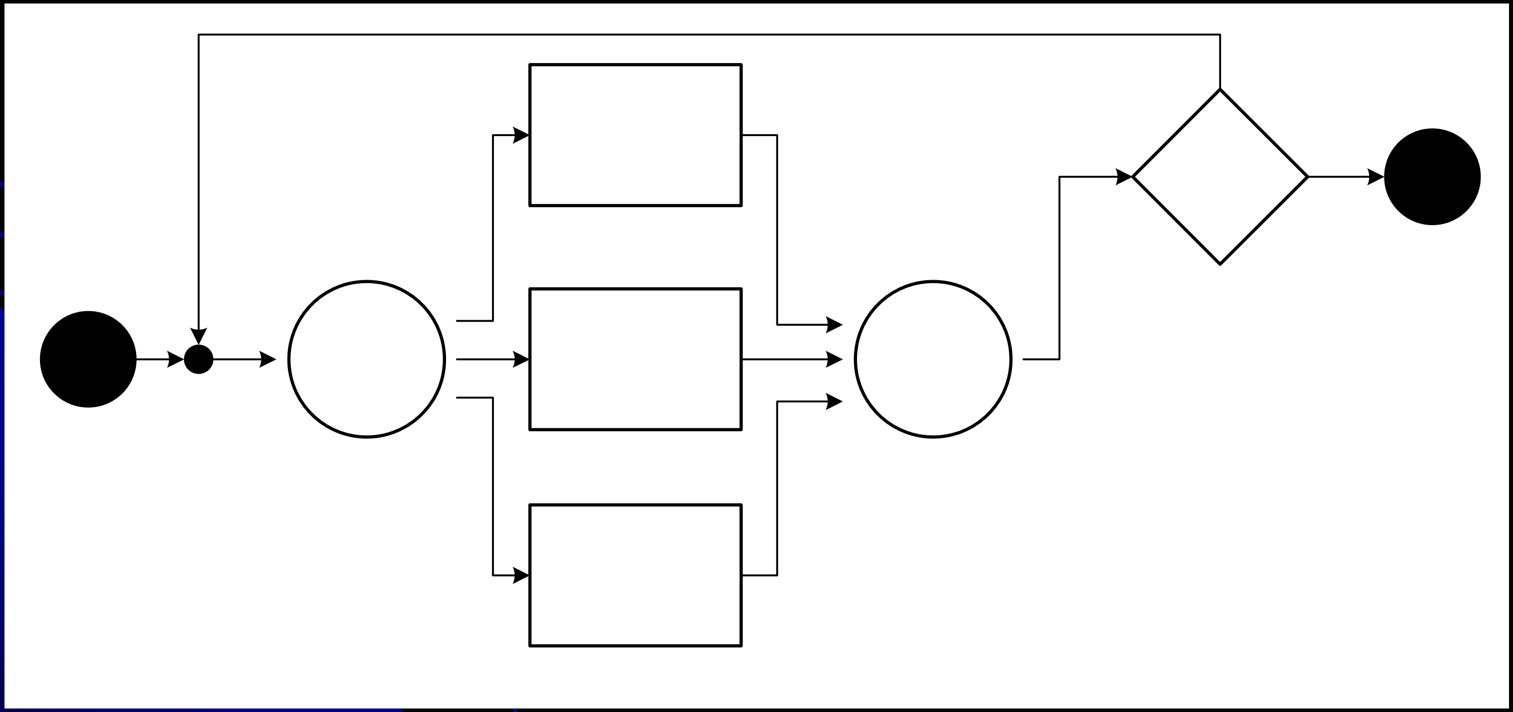
Mode Transition Diagrams

- Capture the modal behavior of the spacecraft
- States indicate system modes
- Transitions correspond to events
  - Events can be internal or external
  - Transition occurs on event being raised
- "Function" associated with each state
  - Models the spacecraft behavior executed while in that state



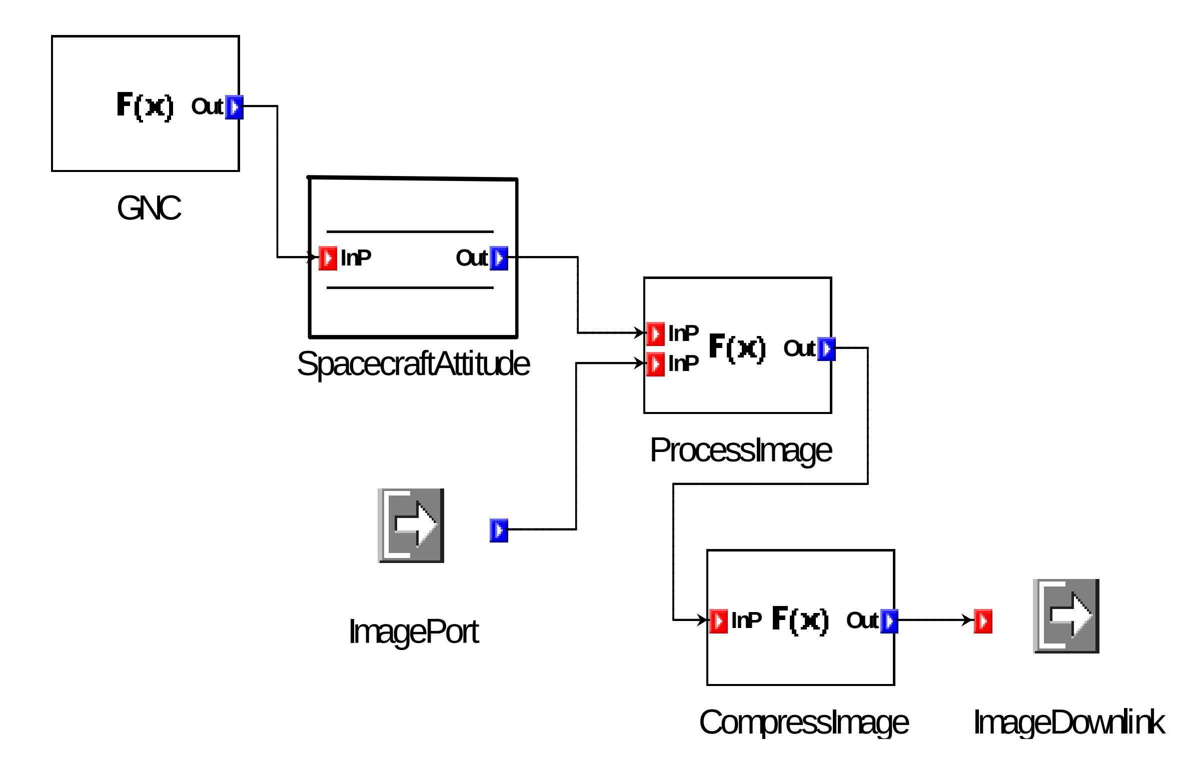
Functional Flow Block Diagrams

- FFBDs define the order of execution of system functions
- Model concurrency, sequencing and iteration through simple associations
- Hierarchical: A function box can be another FFBD



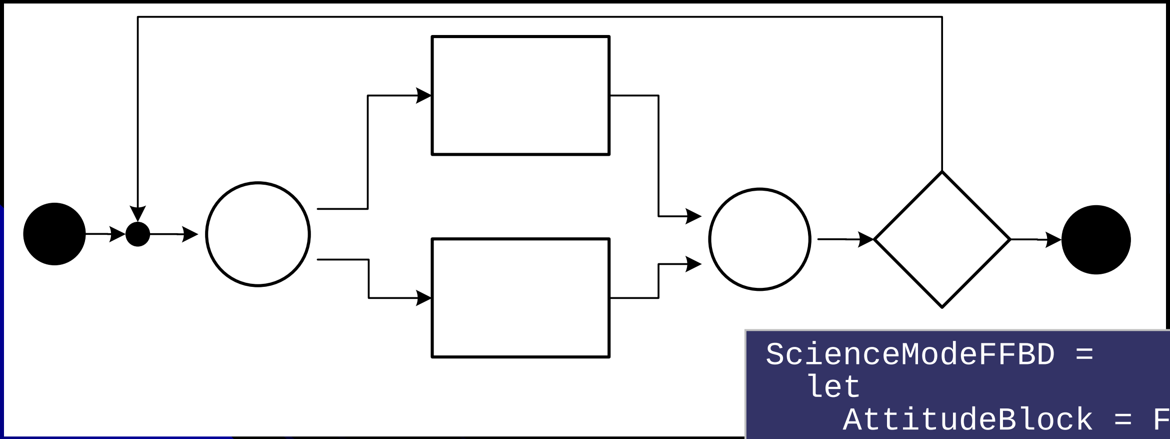
Dataflow Diagrams

- Dataflow diagrams capture data exchange and sharing between functions
- Hierarchical function definition supported in dataflow view
  - Input-Output Transfer functions
  - FFBDs
- External ports capture "external" data sources/sinks
  - ex. sensors, telemetry system



From Diagrams to CSP

- GME model traversal interfaces used to create model interpreters
- Interpreter prototype under construction to automatically generate CSP code from captured diagrams



```
ScienceModeFFBD =
  let
    AttitudeBlock = FFBDblock(cmd_att, set_attitude)
    ScienceBlock = FFBDblock(sci_in_req, sci_out_ack)
    FFBD =
      (begin_ffbd.science ->
        FFBDiteration(get_modestate,diff(Mode,{science}),
          FFBDor({AttitudeBlock, ScienceBlock}));
            end_ffbd.science -> FFBD)
      [] (end_ffbd.science -> FFBD)
  within
    ((AttitudeCommand ||| Science)
     [|{|cmd_att,set_attitude, sci_in_req,sci_out_ack|}|]
    FFBD) \ {|sci_in_req, sci_out_ack|}
```

Summary

- Analytical tools can help designers gain confidence in system-level designs
  - Analysis requires formal semantics
- SDW bridges the gap between formal semantics and intuitive visual constructs
  - builds on **industrially-proven** formal methods
  - allows rigorous **system-level analysis**
  - makes system-level analysis **accessible**
- Paper provides a brief example illustrating both the visual constructs and CSP verification