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Analysing gCSP Models Using Runtime and Model Analysis Algorithms

Communicating Process Architectures 2009

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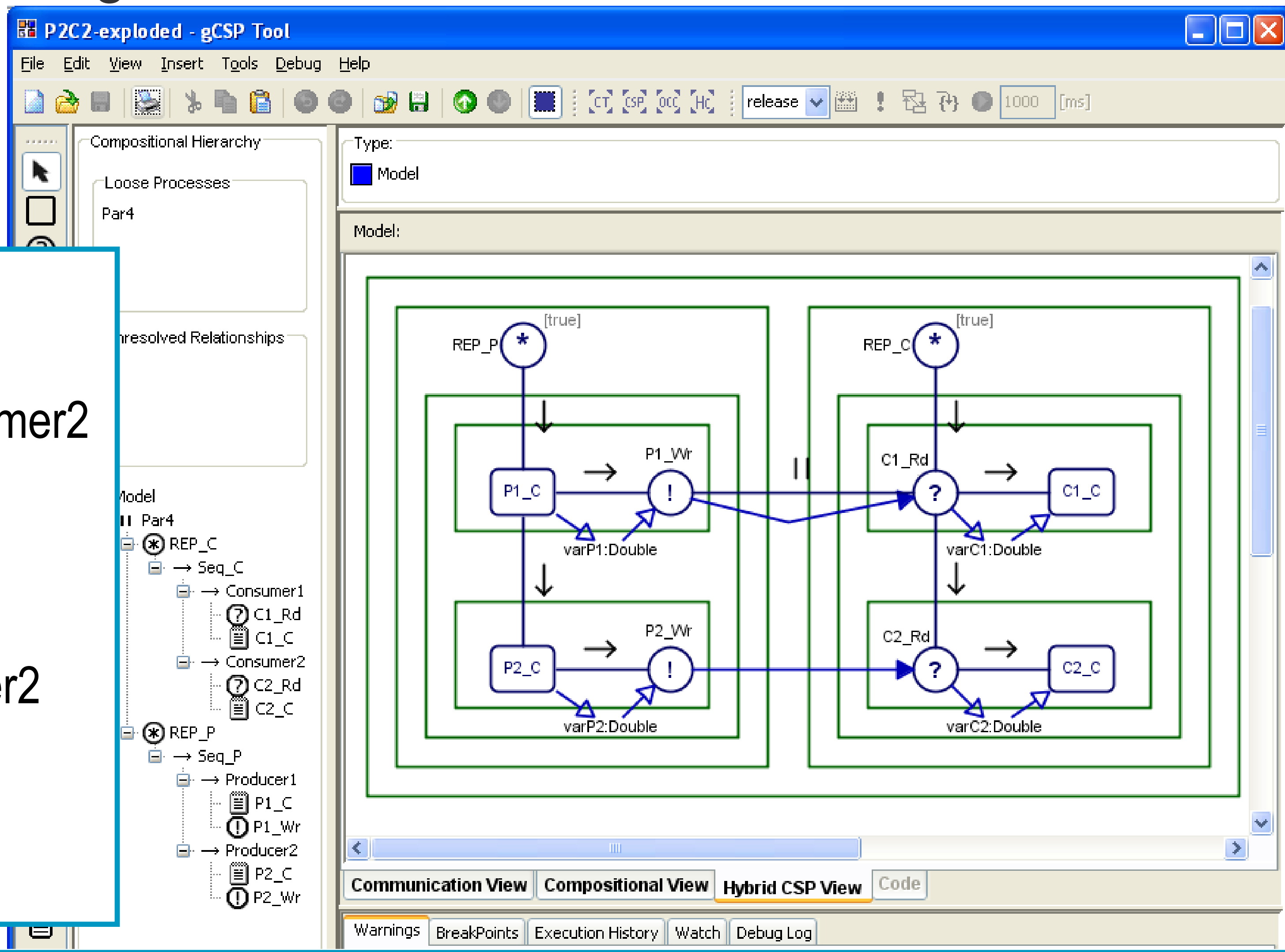
- Introduction
- Runtime Analysis Algorithm
- Model Analysis Algorithm
- Conclusions

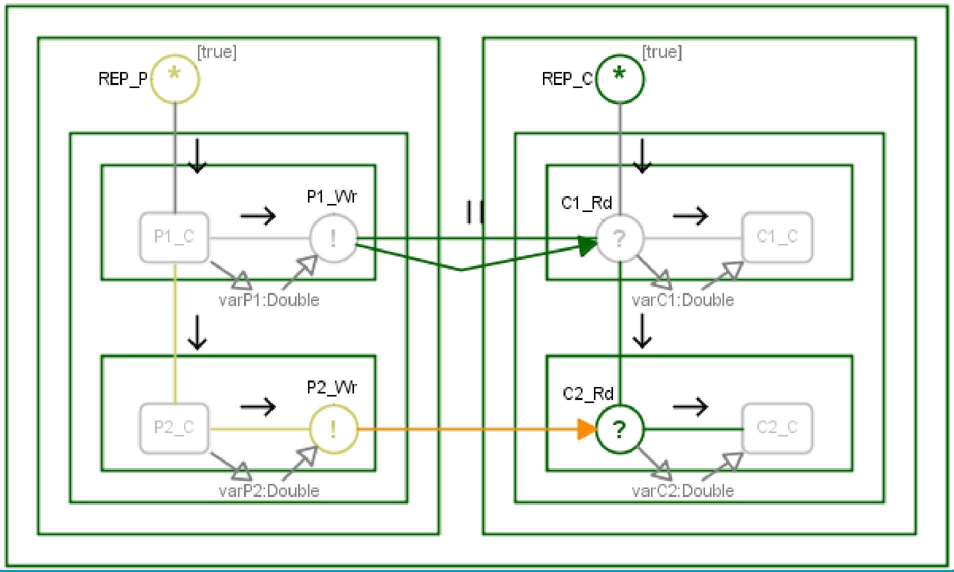
Introduction

- CSP usage at Control Engineering
  - Modelling tool → gCSP

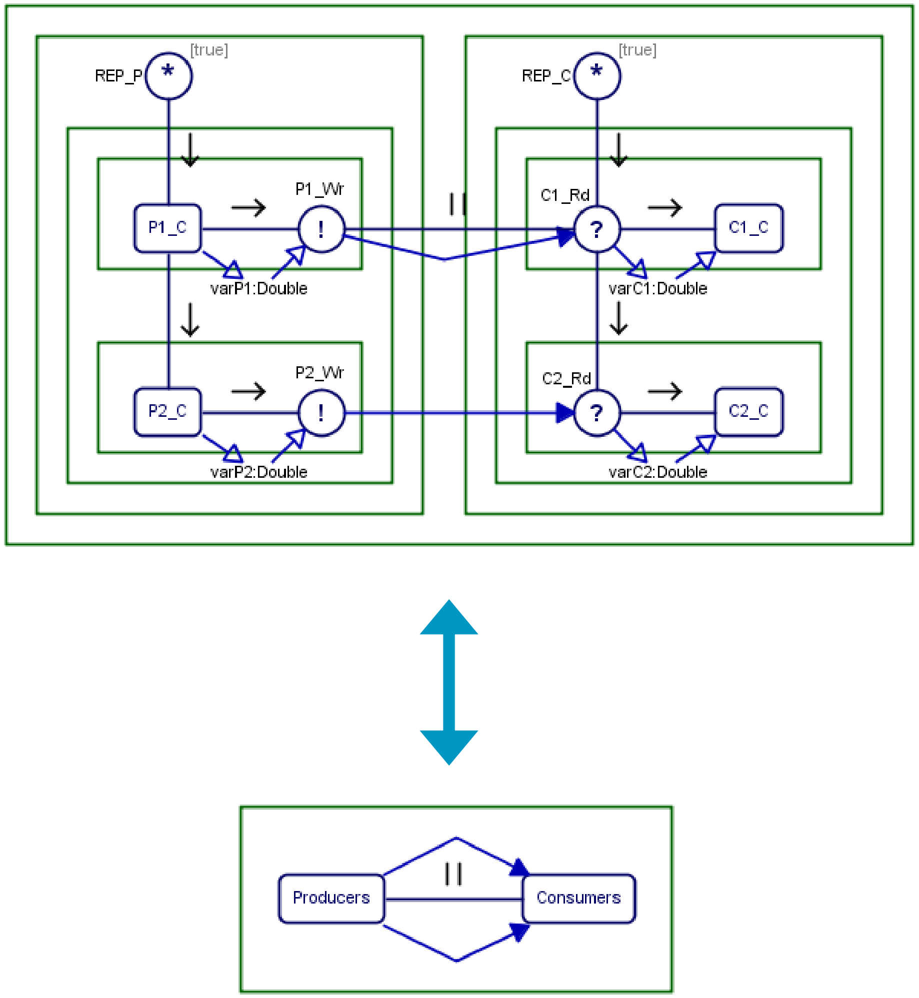


Par4 = REP_P || REP_C
REP_C = Seq_C; REP_C
Seq_C = Consumer1; Consumer2
Consumer1 = C1_Rd; C1_C
Consumer2 = C2_Rd; C2_C
REP_P = Seq_P; REP_P
Seq_P = Producer1; Producer2
Producer1 = P1_C; P1_Wr
Producer2 = P2_C; P2_Wr

- CSP usage at Control Engineering
  - Modelling tool → gCSP
    - Code generation for (robotic) controllers
      - Using Communicating Threads (CT) library
    - Debugging possibilities while running the code
      - Animating the model (processes and channels)
      - Stepping through model, while showing channel values



- Designer Point of View
  - Detailed modelling
  - Lots of small processes
- Executing Point of View
  - Fast code
  - A few bigger processes
- Both Points of View conflict!

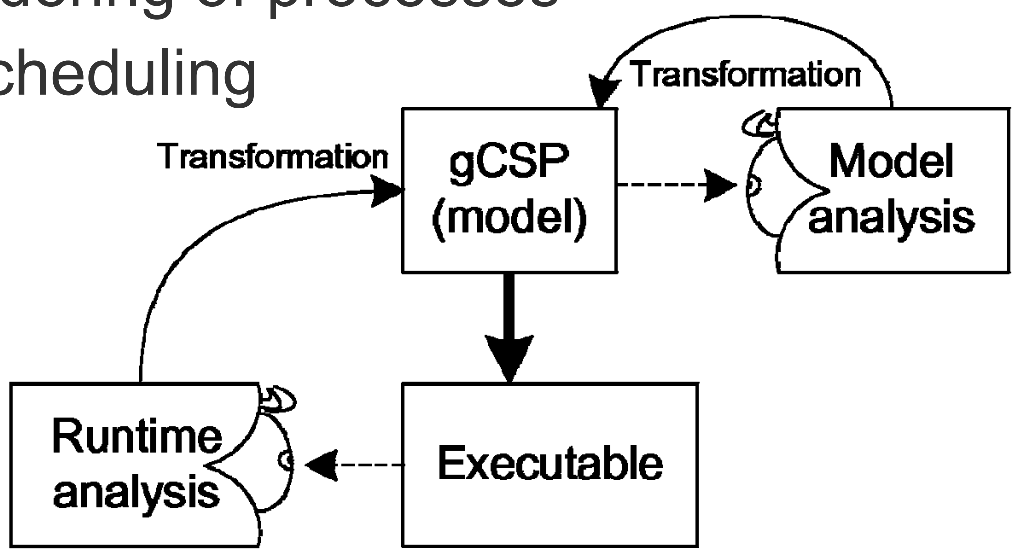


Introduction Solution

- Translate Designer PoV to Executing PoV

- Requires
  - Analysis of the gCSP model
  - Model transformation

- Solution: two analysis algorithms
  - Runtime analysis for static ordering of processes
  - Model analysis for process scheduling



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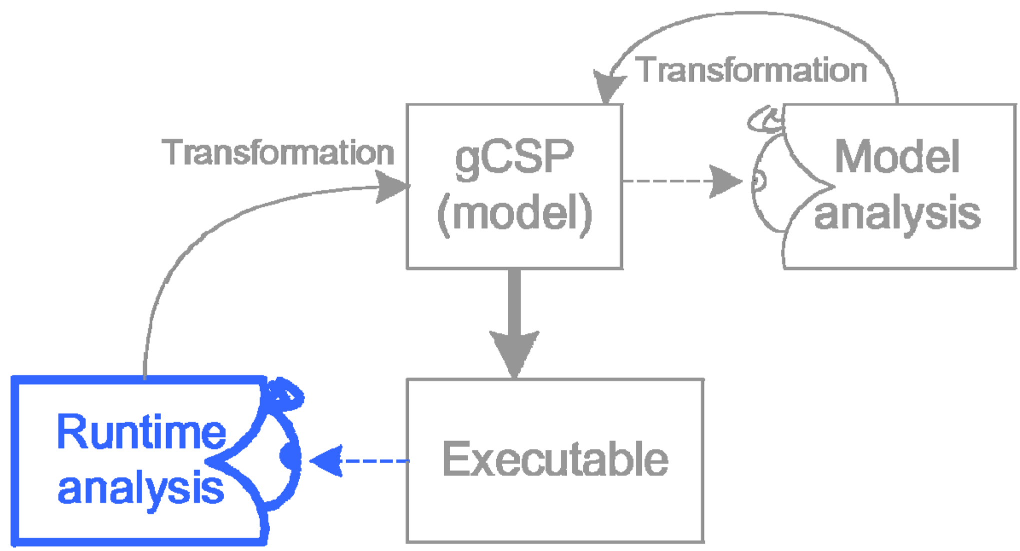
Runtime Analysis Algorithm

- Why static ordering of processes
  - No complex scheduler required
  - Possibility for grouping of processes
- Goal of Runtime Analysis Algorithm
  - Find a static running order for the processes



Runtime Analysis Algorithm Processes

- Process states
  - New — Process is created
  - Ready — Process is ready to be started
  - Running — Process is started and still running
  - Blocked — Process is blocked
  - Finished — Process is ended

- Algorithm mainly uses Finished state to determine the static running order

Runtime Analysis Algorithm Notations

- Set of chains
  - Clear view of groups of processes
  - Cross-Reference types
    - To other chain
    - To start of same chain
  - Comparable with a CSP Trace

```
D → C → F → B → (B,D*)
B → E → A → C → (D)
[start] → A → B → C → D → (B)
```

- Traces
  - Finished processes of running model
  - For demonstration purposes

$A \rightarrow B \rightarrow C \rightarrow D \rightarrow B \rightarrow E \rightarrow A \rightarrow C \rightarrow E \rightarrow A \rightarrow C \rightarrow D \rightarrow C \rightarrow F \rightarrow \ldots$

Runtime Analysis Algorithm Algorithm

- Process Ordering Rules
  - Chains with no cross-refs (the active chain is not finished yet)
    - Add processes to chain

- Rules
  - If the state of a process changes to Finished add it to the end of the active chain.
  - If a process is Finished and is already present in the active chain, it will become a cross-reference of this chain pointing to a chain starting with this process.

A → B → C → B → D → E → F → B

B → D → E → F → (B*)

[start] → A → B → C → (B)

Runtime Analysis Algorithm Algorithm

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- Process Ordering Rules
  - Chains with cross-refs (the active chain got finished already)
    - Perform validation on chains

- Rules
  - If the active process does not match the Finished process the chain must be split.

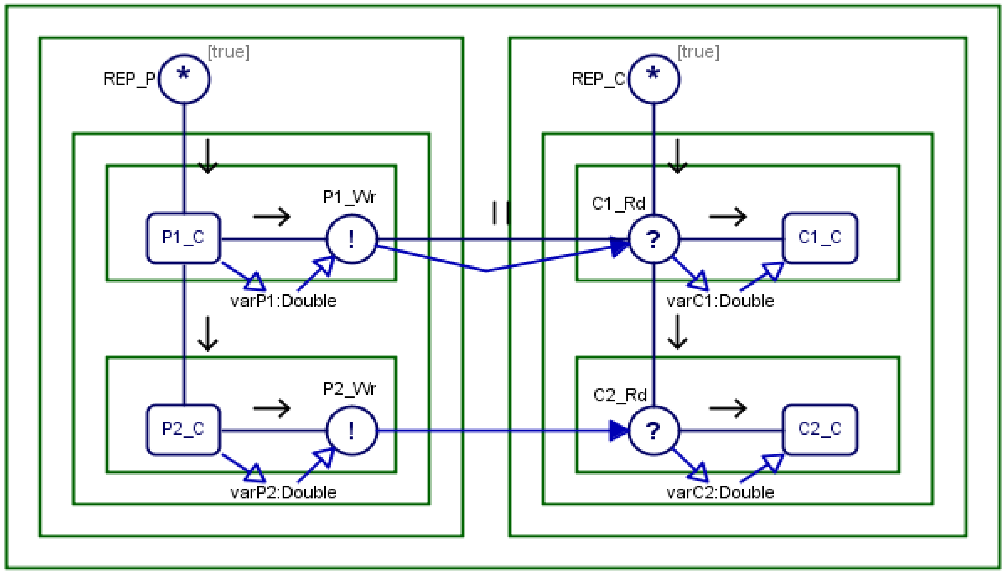
Rules for 'chains with no cross-references' applied

… → *D* → *E* → *F* → *B* → *D* → *G* → *H*

```
G → H
E → F → (B)
B → D → (E,G)
[start] → A → B → C → (B)
```

Runtime Analysis Algorithm Results

- Set of chains as expected
  - All processes could be placed in one big process
    - Writer-Reader combinations can be removed
    - Channels become internal variables

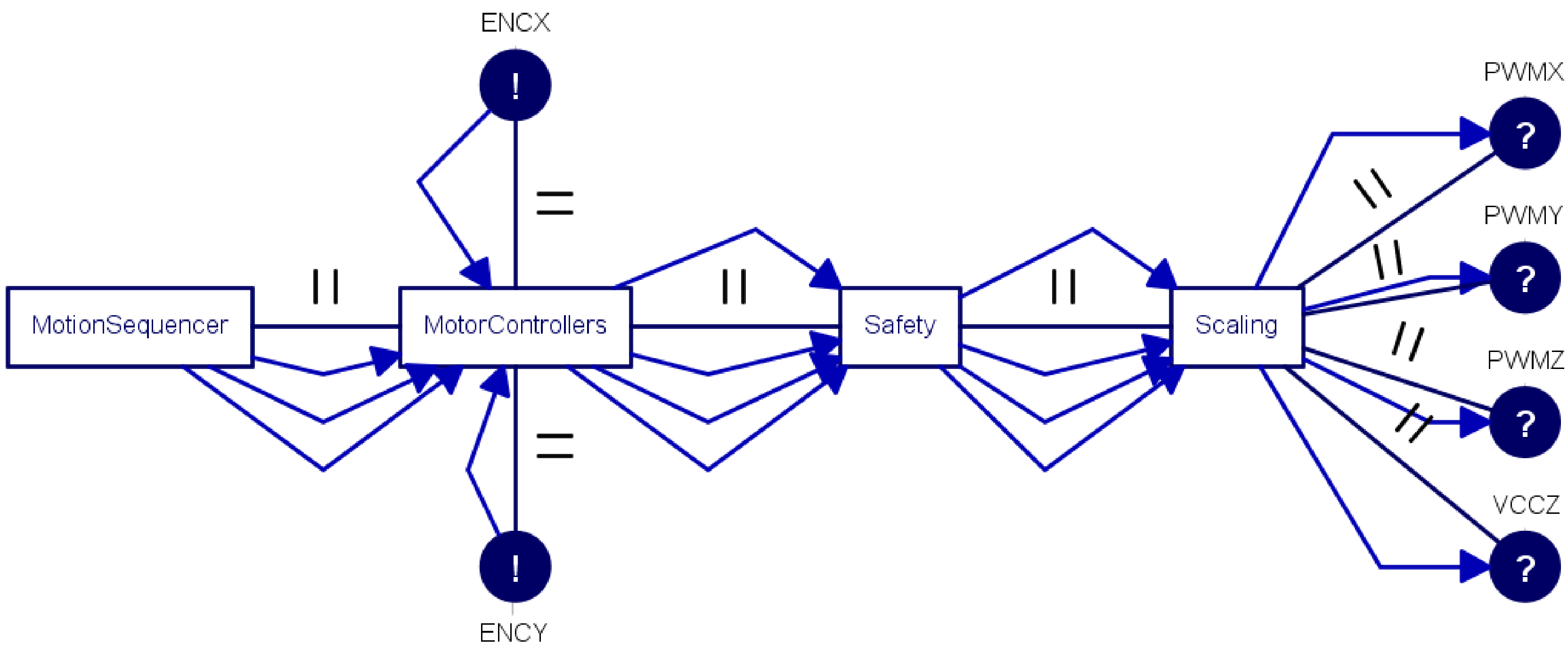



```
P1_C →C1_Rd →C1_C →P1_Wr →P2_C →
      P2_Wr →C2_Rd →C2_C →(P1_C*)
[start]→(P1_C)
```

Runtime Analysis Algorithm Results

- Scalability of the algorithm
  - Complex traces
    - Hard to verify results
  - Static ordering available

- Working Cartesian plotter model



- Working Cartesian plotter model

1 Sc_Rd8 → DoubletoBooleanConversion → Sc_Wr17 → Sa_Wr8 → Sa_Rd4 → MC_Wr4 → Sa_Rd7 → MC_Wr7 → Sa_Rd6 → MC_Wr6 → Sa_Rd5 → MC_Wr5 → Sa_Rd_ESX2_2 → Sa_Rd_ESX2_1 → Sa_Rd_ESX1_2 → Sa_Rd_ESX1_1 → MC_Rd12 → MC_Rd13 → Safety_X → Sa_Rd_ESY1 → Sa_Rd_ESY2 → Safety_Y → Safety_Z → MC_Rd1 → MS_Wr1 → MC_Rd2 → MS_Wr2 → Sa_Wr9 → Sc_Rd9 → MC_Rd3 → LongtoDoubleConversion → Controller → MS_Wr3 → Sc_Rd10 → Sa_Wr10 → (Sc_Rd11)

2 Sc_Rd11 → DoubletoShortConversion → Sc_Wr14 → Sc_Wr15 → Sc_Wr16 → Sa_Wr11 → (Sc_Rd8, HPGLParser)

3 MC_Rd12 → MC_Rd13 → Sa_Rd_ESX2_2 → Sa_Rd_ESX2_1 → Sa_Rd_ESX1_2 → Sa_Rd_ESX1_1 → MC_Rd1 → MS_Wr1 → Safety_X → Sa_Rd_ESY1 → Sa_Rd_ESY2 → Safety_Y → Safety_Z → MC_Rd2 → MS_Wr2 → MC_Rd3 → LongtoDoubleConversion → Controller → MS_Wr3 → Sa_Wr9 → Sc_Rd9 → Sc_Rd10 → Sa_Wr10 → (HPGLParser)

4 HPGLParser → (MC_Rd12, Sc_Rd11)

→ [start] → MC_Rd12 → MC_Rd13 → HPGLParser → MS_Wr1 → MC_Rd1 → MC_Rd2 → MS_Wr2 → MC_Rd3 → LongtoDoubleConversion → Controller → MS_Wr3 → MC_Wr5 → Sa_Rd5 → MC_Wr6 → Sa_Rd6 → MC_Wr7 → Sa_Rd7 → MC_Wr4 → Sa_Rd4 → (HPGLParser)

Contents

Model Analysis Algorithm

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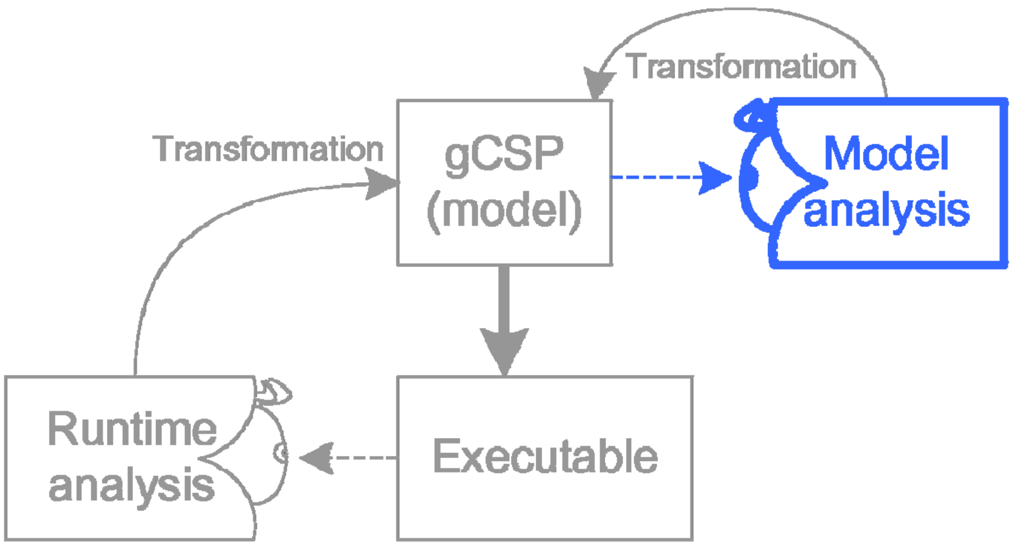
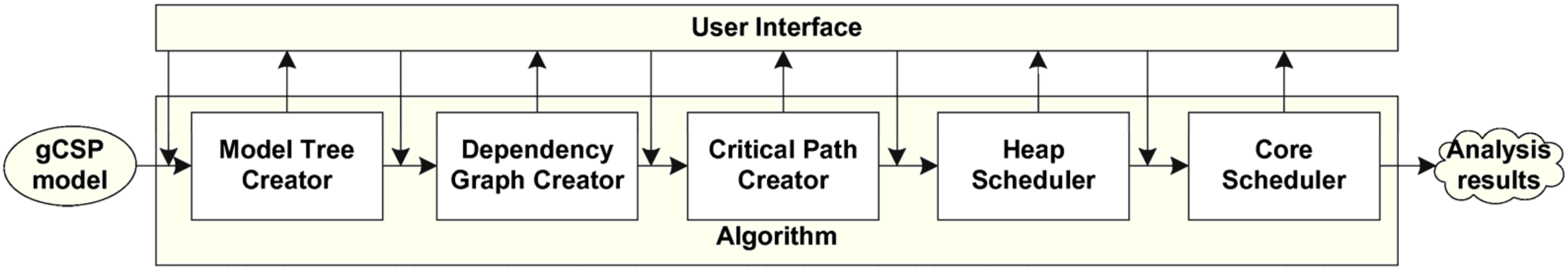
- More towards model analysis/ model transformation
  - What processes are related?
  - How to schedule large models onto a target system?

- Goal
  - Schedule processes on cores/ networked nodes

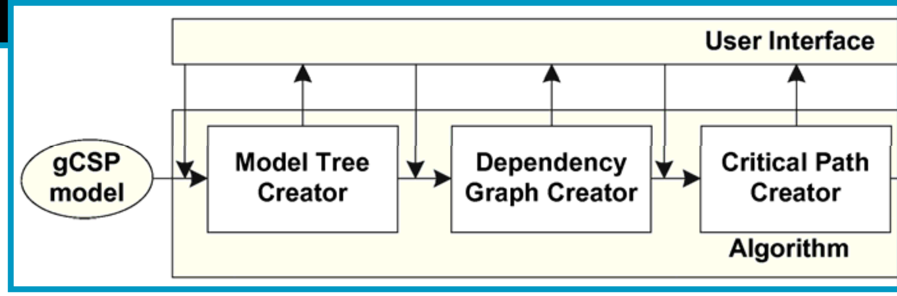


Model Analysis Algorithm Architecture

- Algorithm Architecture
  - Build modular
- gCSP model & User Interface feed the algorithm with data
  - Process weights (or execution times)
  - Available cores or networked nodes
  - Communication (setup) time

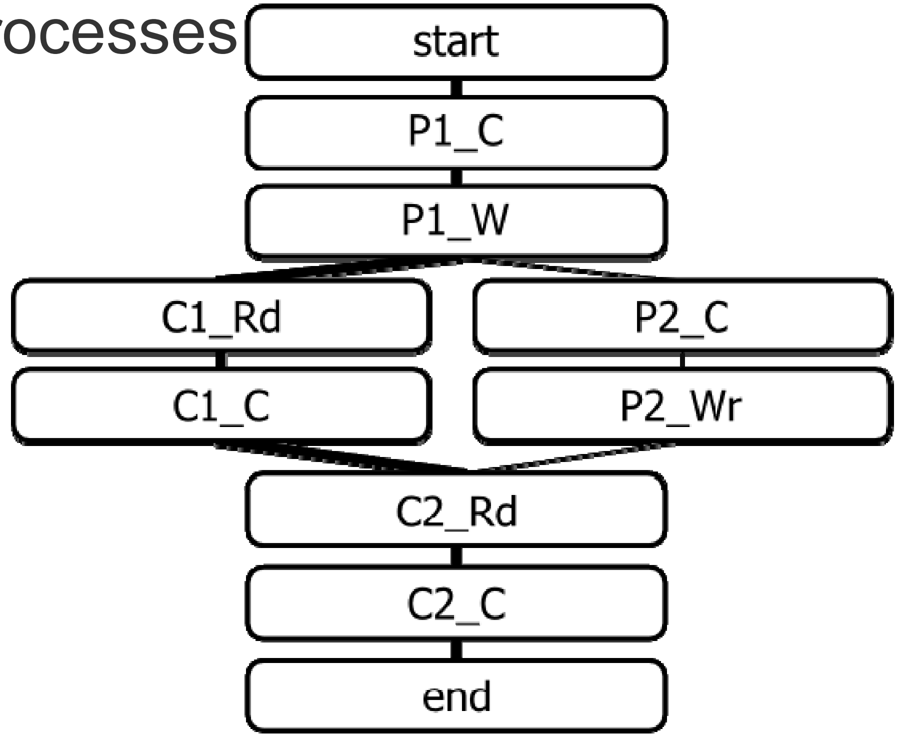


Model Analysis Algorithm Algorithms



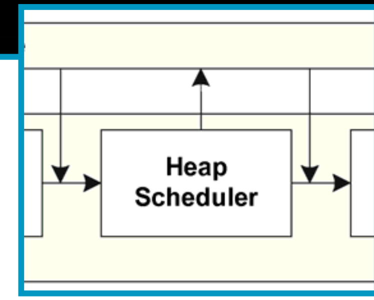
- Model Tree Creator
  - Recreates the model tree
  - Only for displaying purposes for the user interface

- Dependency Graph Creator
  - Finds dependencies between processes
    - Sequential relations
    - Channels

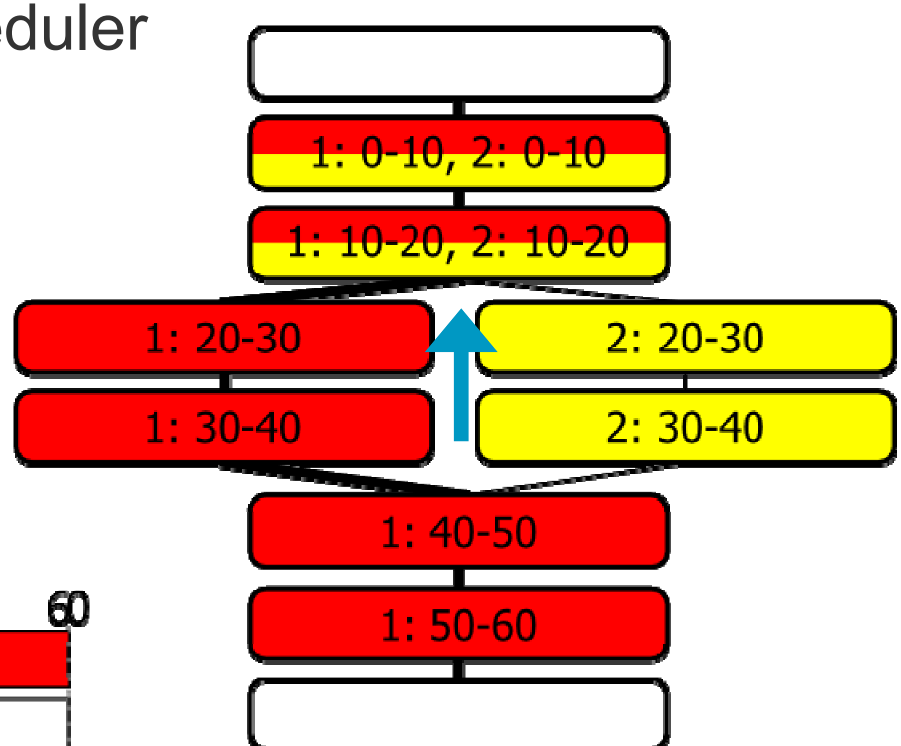


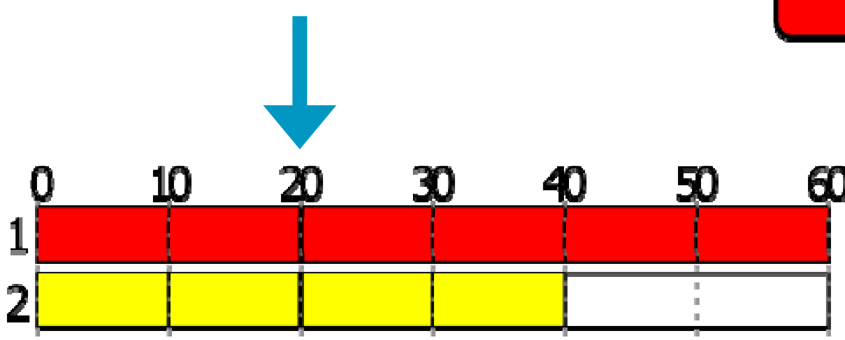
- Critical Path Creator
  - Finds the critical path using the dependencies

Model Analysis Algorithm Heaps

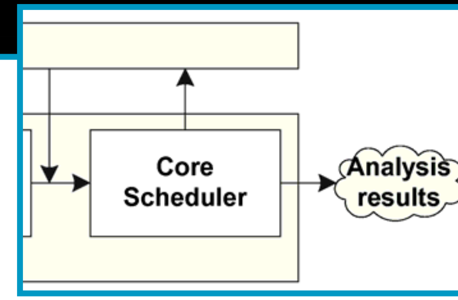


- Heaps
  - Groups of ‘related’ processes
  - Influenced by
    - Process weight
    - Communication (setup) time
  - Reduce complexity of core scheduler
- Index blocks
  - Subdivision of heaps
  - When multiple outgoing dependencies are available

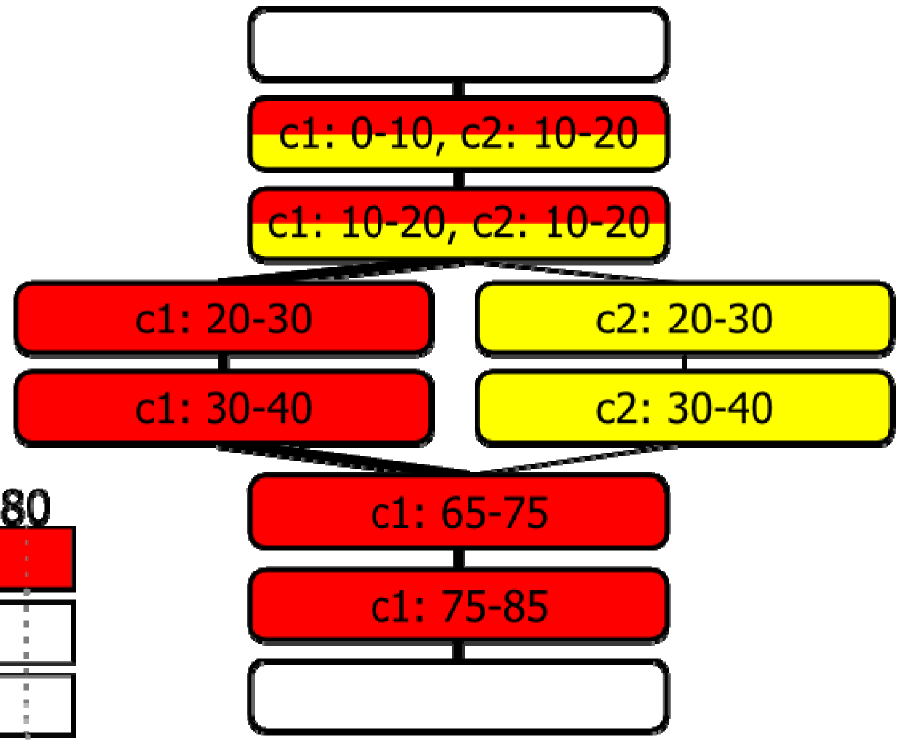


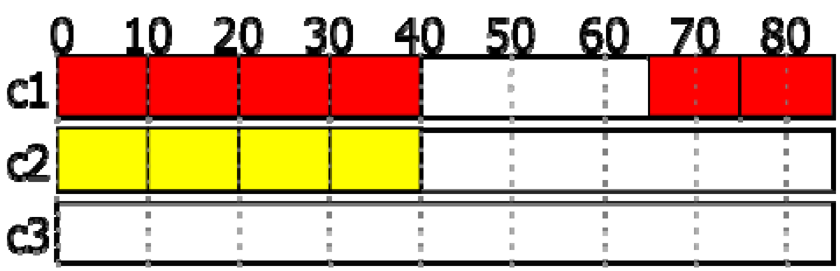


Model Analysis Algorithm Cores



- Cores
  - Groups of processes to be scheduled on the same core/ networked node
  - Find optimum for end time
    - Amount of cores
    - Relative speed of cores





Model Analysis Algorithm Results

- The processes are optimally scheduled
  - For the given process weights
  - For the given communication times
  - For the given target systems (mostly)

- Scalable for models of real-life setups
  - Cartesian plotter model
  - Production cell model
    - 597 Processes
    - 210 Heaps
    - ~50 Cores for optimal ending time

Model Analysis Algorithm Results

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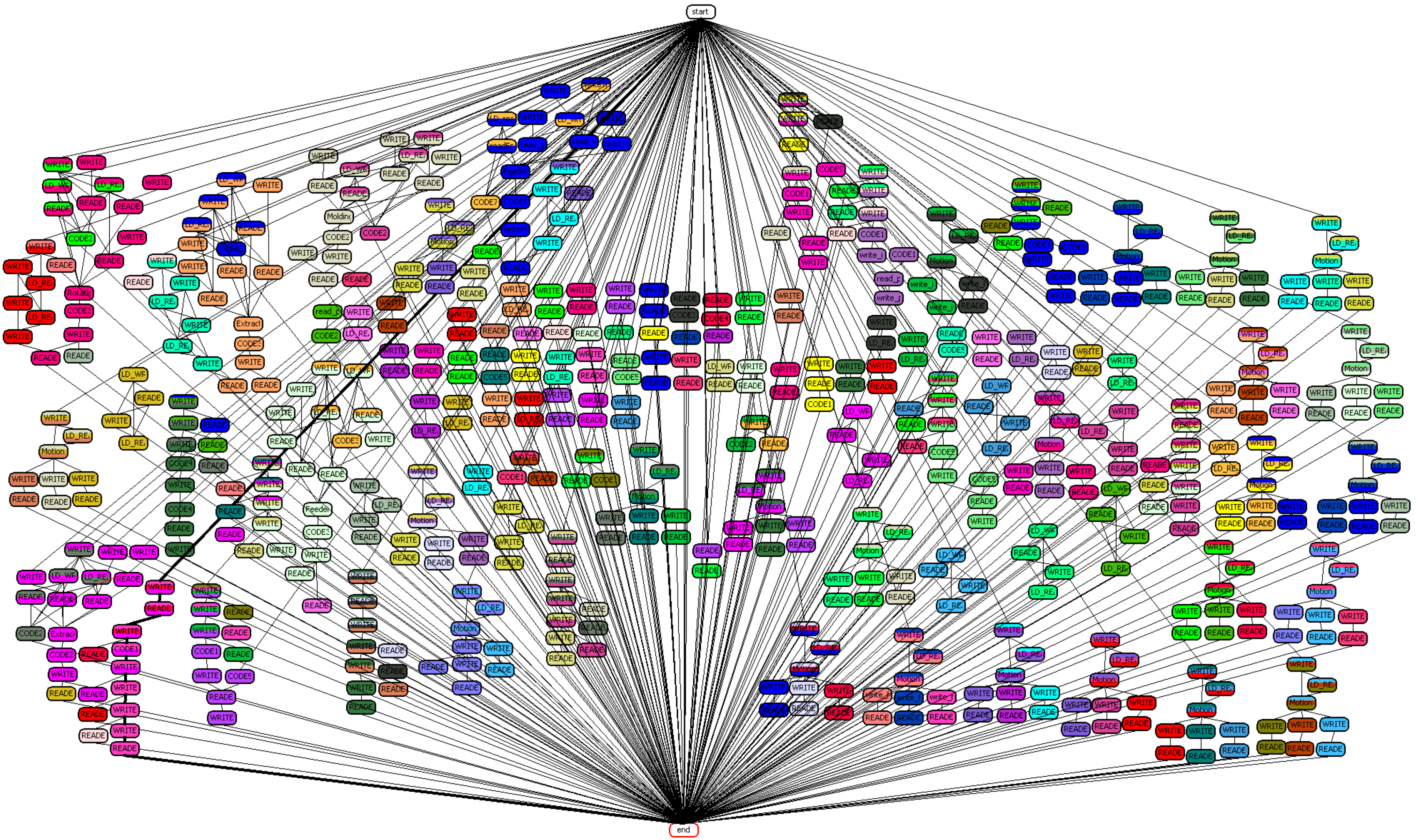

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Conclusions

- Both analysis algorithms work as expected
  - Functional
  - Scale well
- Both analysis algorithms complement each other
  - Runtime analysis algorithm
    - Groups processes into bigger processes
    - Reduces the amount of context switches
  - Model analysis algorithm
    - Schedules processes onto multiple cores
    - Reduces the amount of network communication
  - Both reduce execution time
    - Without losing concurrency aspects

Recommendations

- Refinements are necessary
  - Better representation of the results
  - Include more CSP constructs
  - Support for allocating specific processes on a core
  - Better support for networked nodes

- Next steps
  - Include model transformations after the analysis phase
  - Implement the algorithms in the gCSP2 tool

Runtime Analysis Algorithm Algorithm

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- The active chain should be split at process **B** when process p is unexpected, but a chain starting with process **B** is present.
  - Compare the processes after **B** with the chain starting with process **B** → equal!
  - Remove the remaining process (**E**) in the active chain starting at process **B**.
  - Add the cross-references (**G**) to the chain starting with **B** if they are not present at this chain.
  - Create a new chain starting with **I** and make it the active chain.

```
G → H → B → D → (G*)
E → F → (B)
B → D → (E,G)
A → B → C → (B)
```

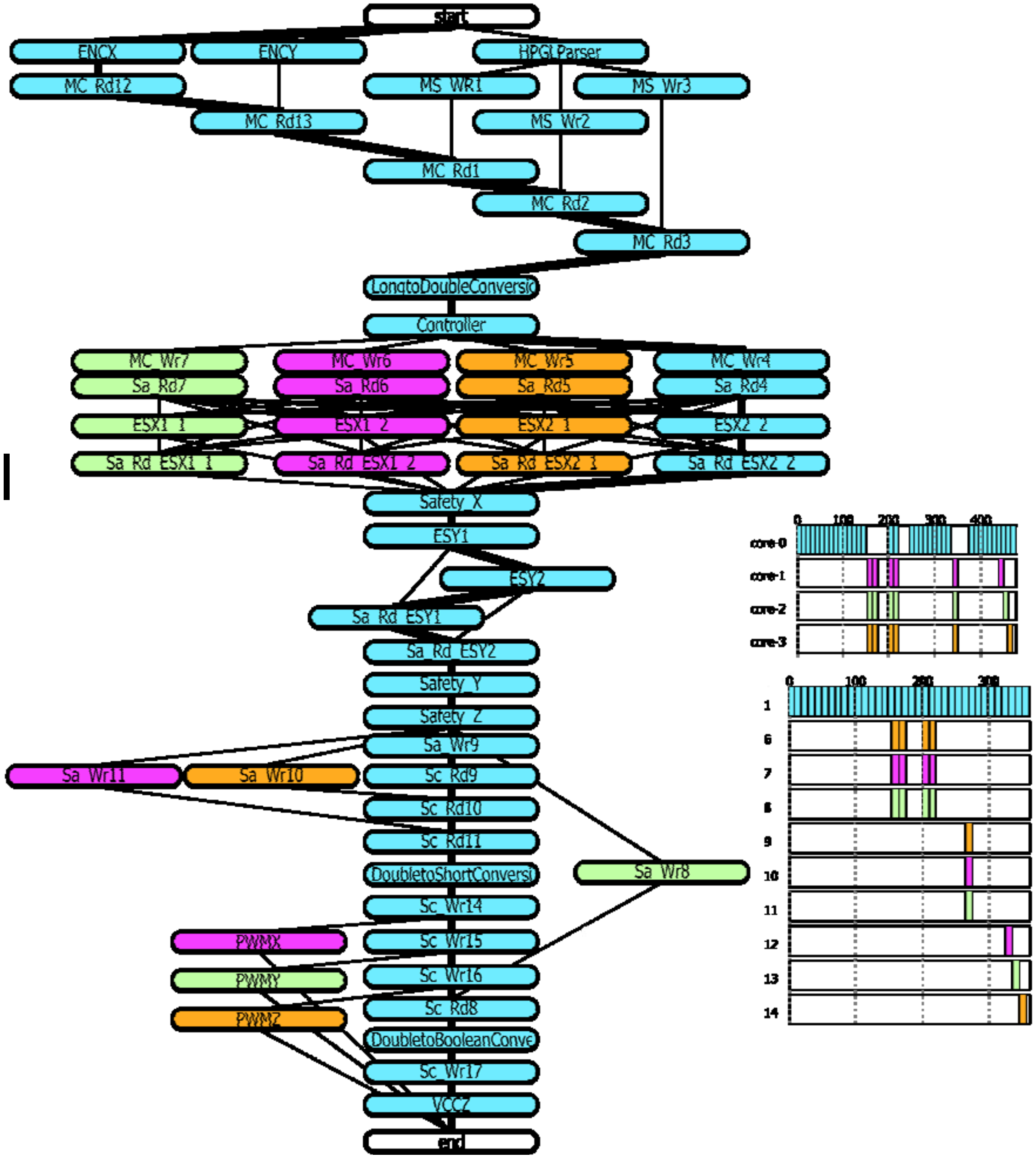
```
I
G → H → (B, I)
E → F → (B)
B → D → (E,G)
A → B → C → (B)
```

A → B → C → B → D → E → F → B → D → G → H → B → D → G → H → ***I***

Cartesian plotter

- 56 processes
- 10 heaps
- ~4 cores

- 1 core is almost optimal



Ongoing Work

- gCSP2
  - Eclipse based
  - Much more stable compared to gCSP