Larissa, an Aspect-Oriented Language for Reactive Systems

PhD Defense

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Verimag/Grenoble INP

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Jury

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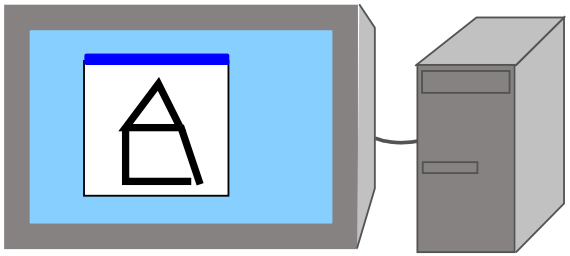
Florence Maraninchi
Karine Altisen

Outline

Aspect-Oriented Programming



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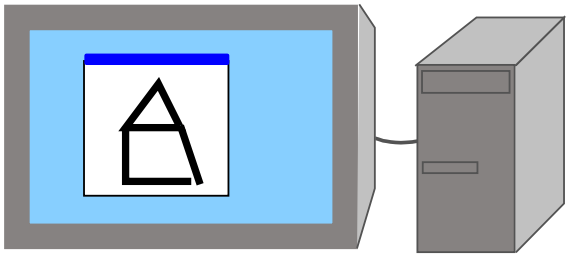
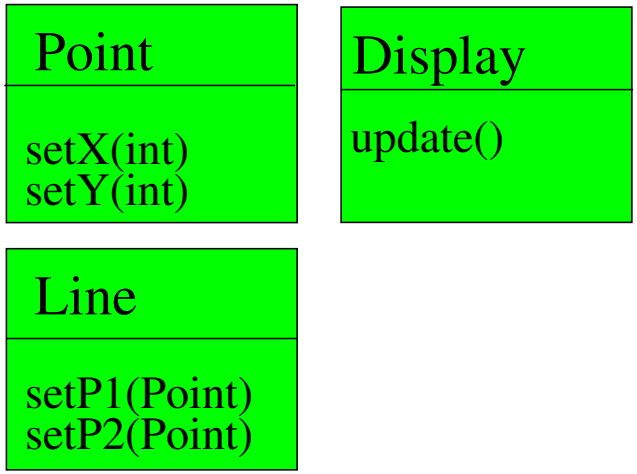
Aspect-Oriented Programming





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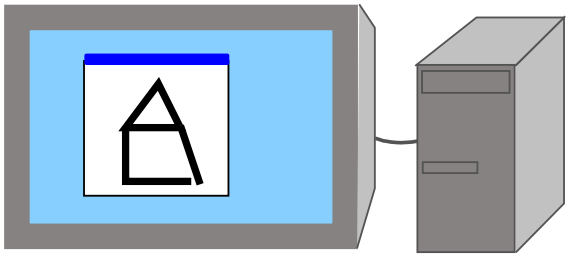

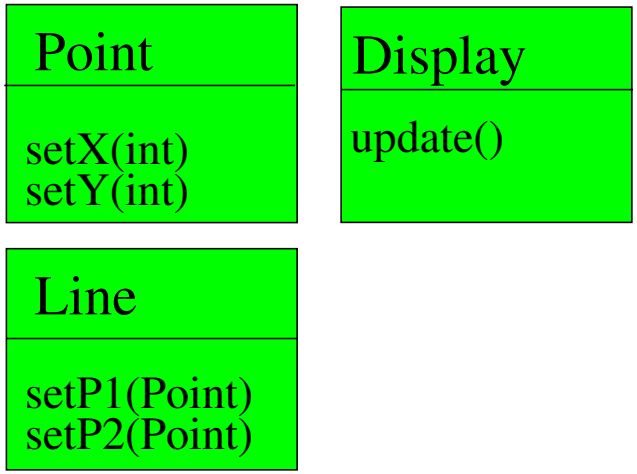

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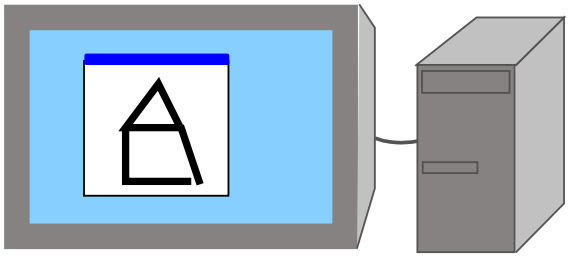

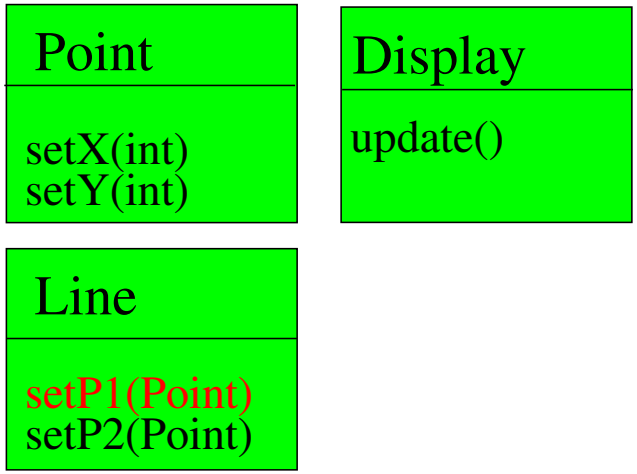

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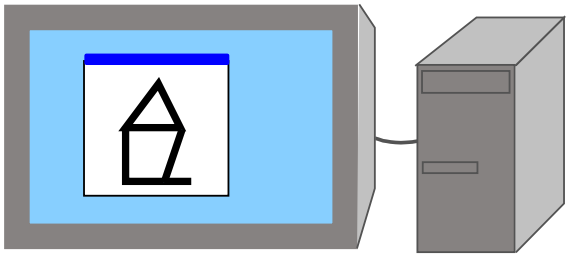

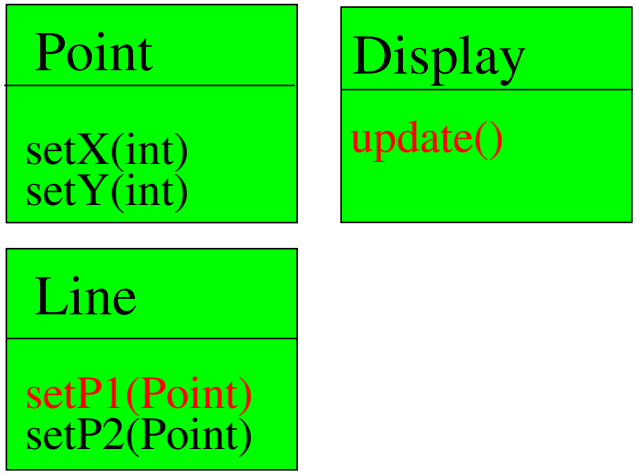

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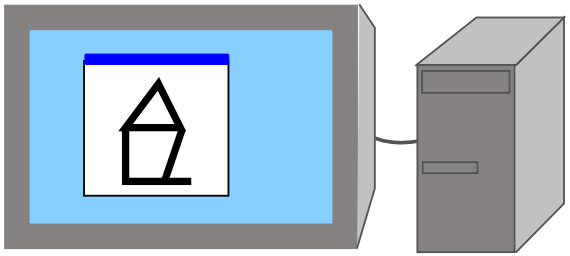

Point
setX(int) setY(int)

Display
update()

Line
setP1(Point) setP2(Point)

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- Solution: Add **update()** to methods
- Bad: scattered code

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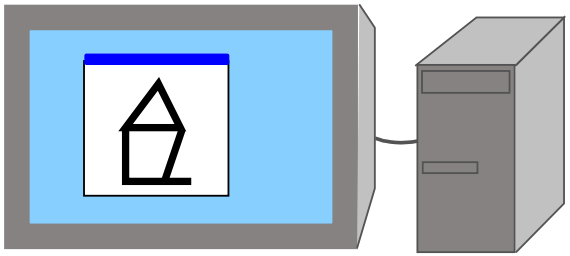

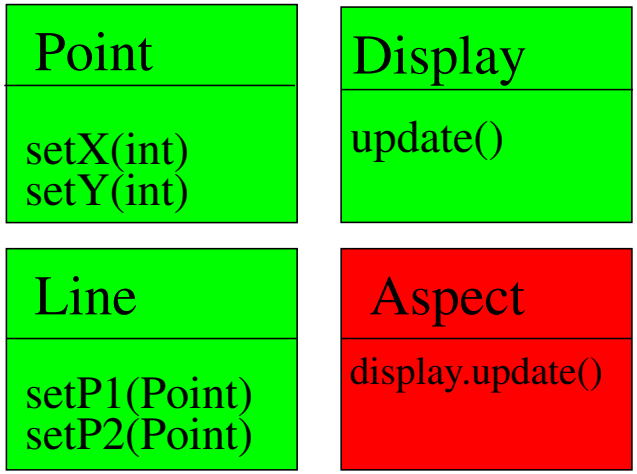

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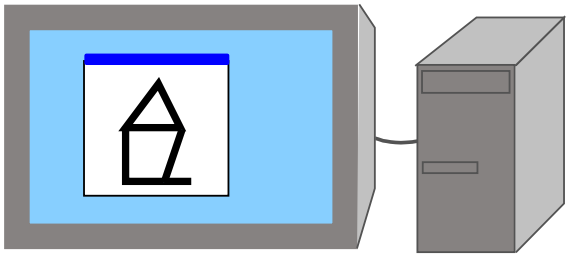

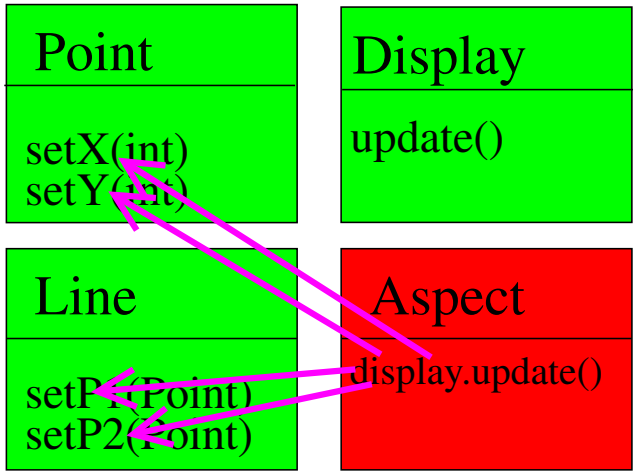

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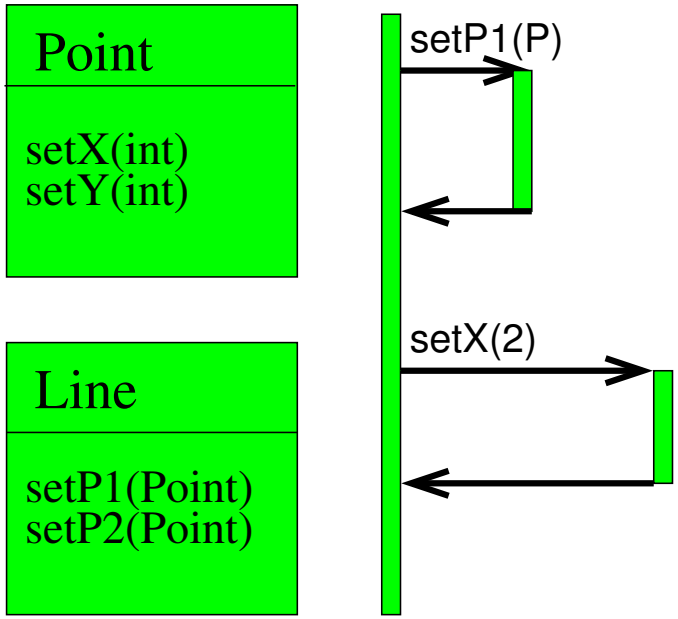
- Idea: put crosscutting code in aspect
- Weave aspect in program

Example in Java and AspectJ



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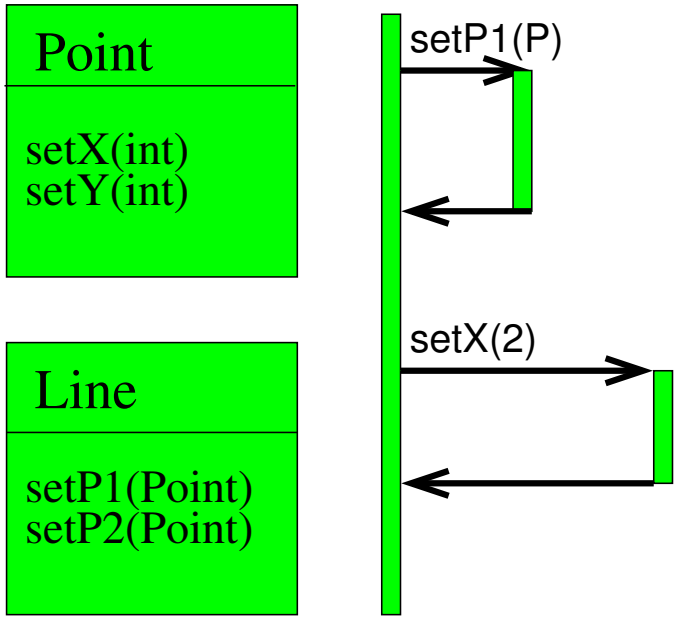


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AOP: Key Concepts

- Join points: where aspects intervene
- Pointcut: select join points
- Advice: what aspect does

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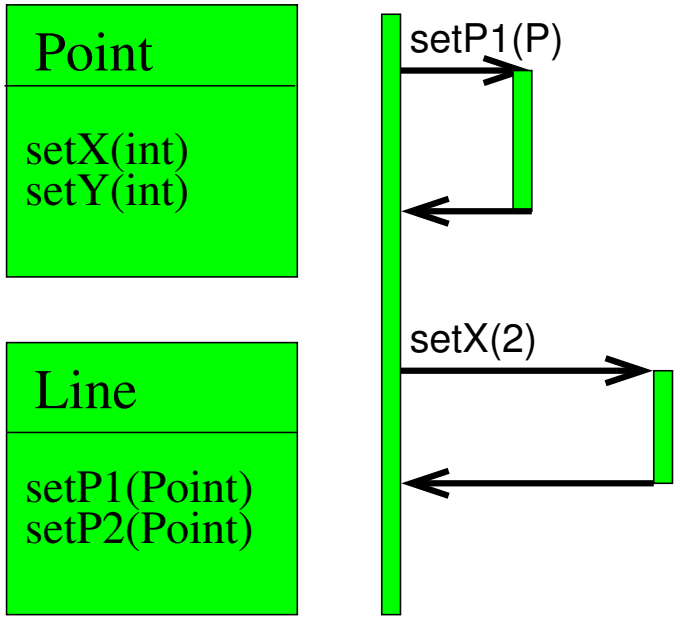


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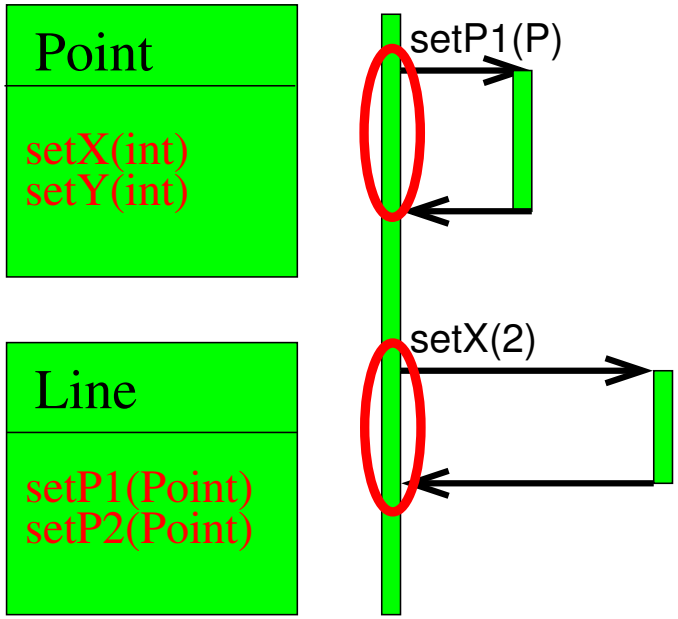


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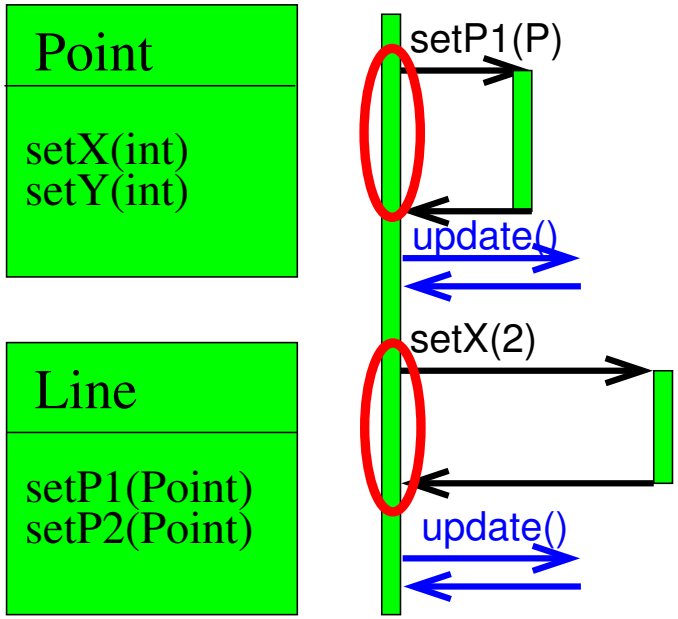


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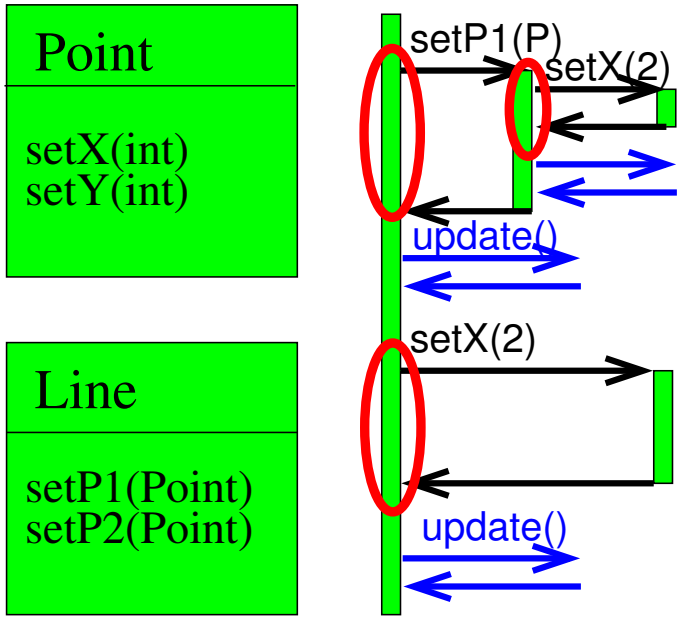


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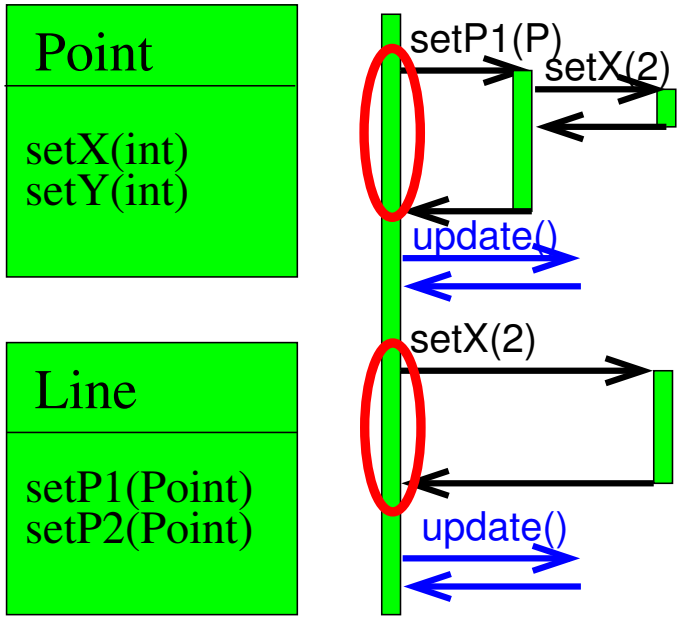


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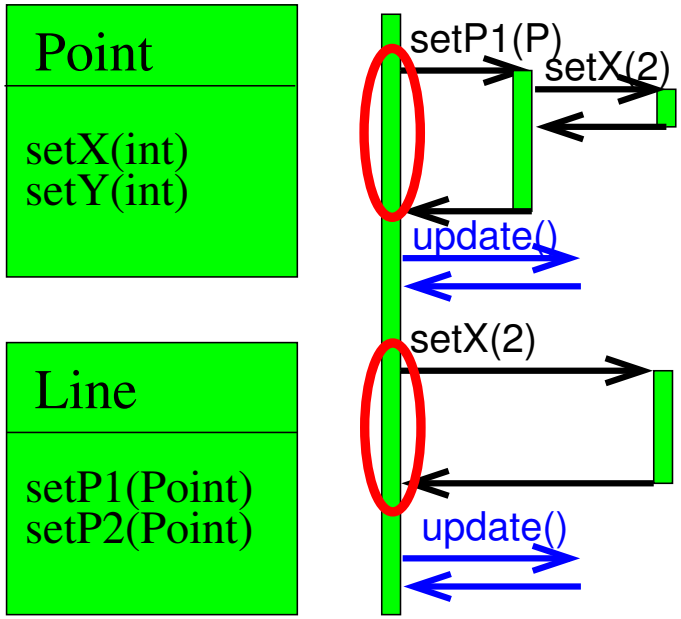


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Conclusion on AspectJ

- Based on lexical elements
- Powerful constructs

Reactive Systems and Synchronous Languages

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- Receive inputs, emit outputs
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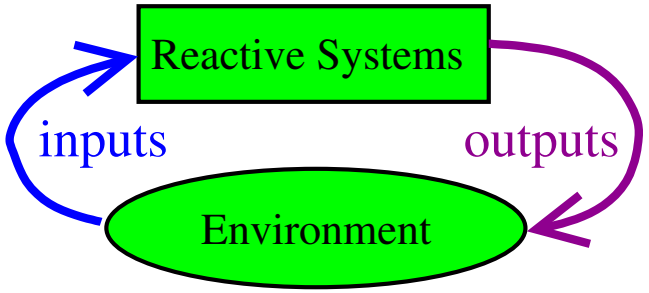

Reactive Systems and Synchronous Languages

- Constant interaction with environment
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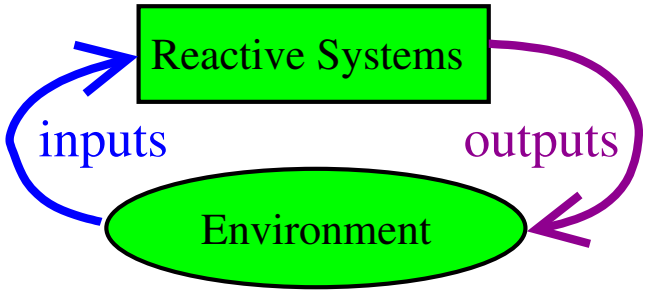
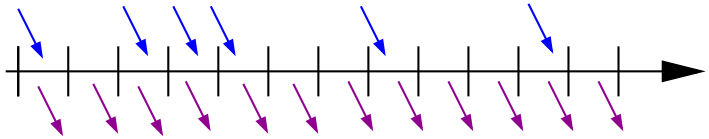
- Synchronous languages: simple semantics, discrete time





A Wristwatch – A Reactive System

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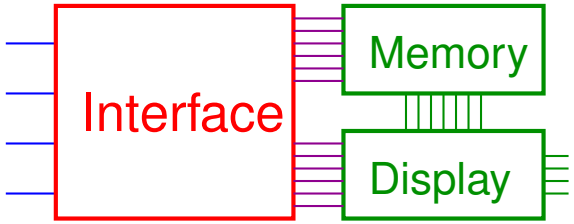
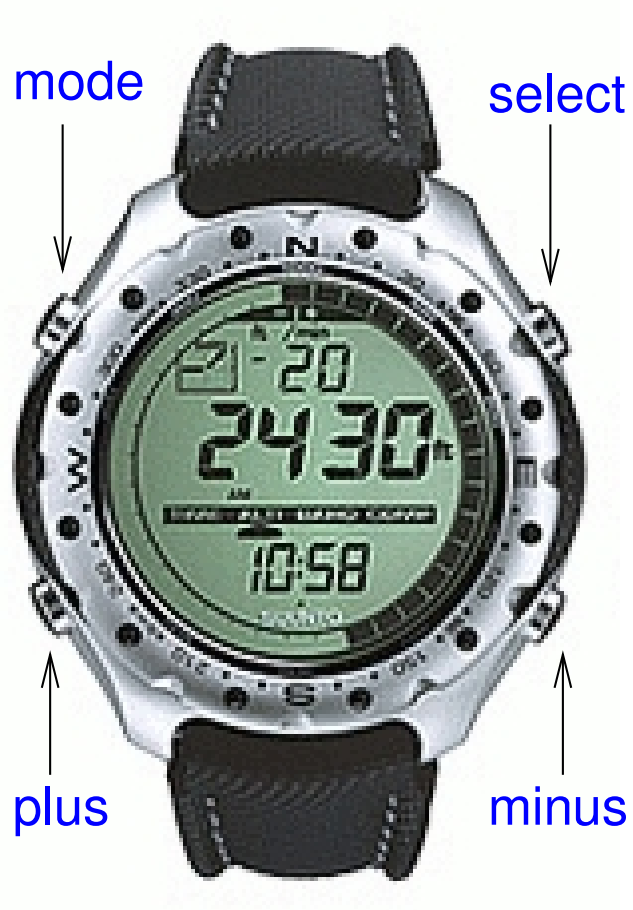
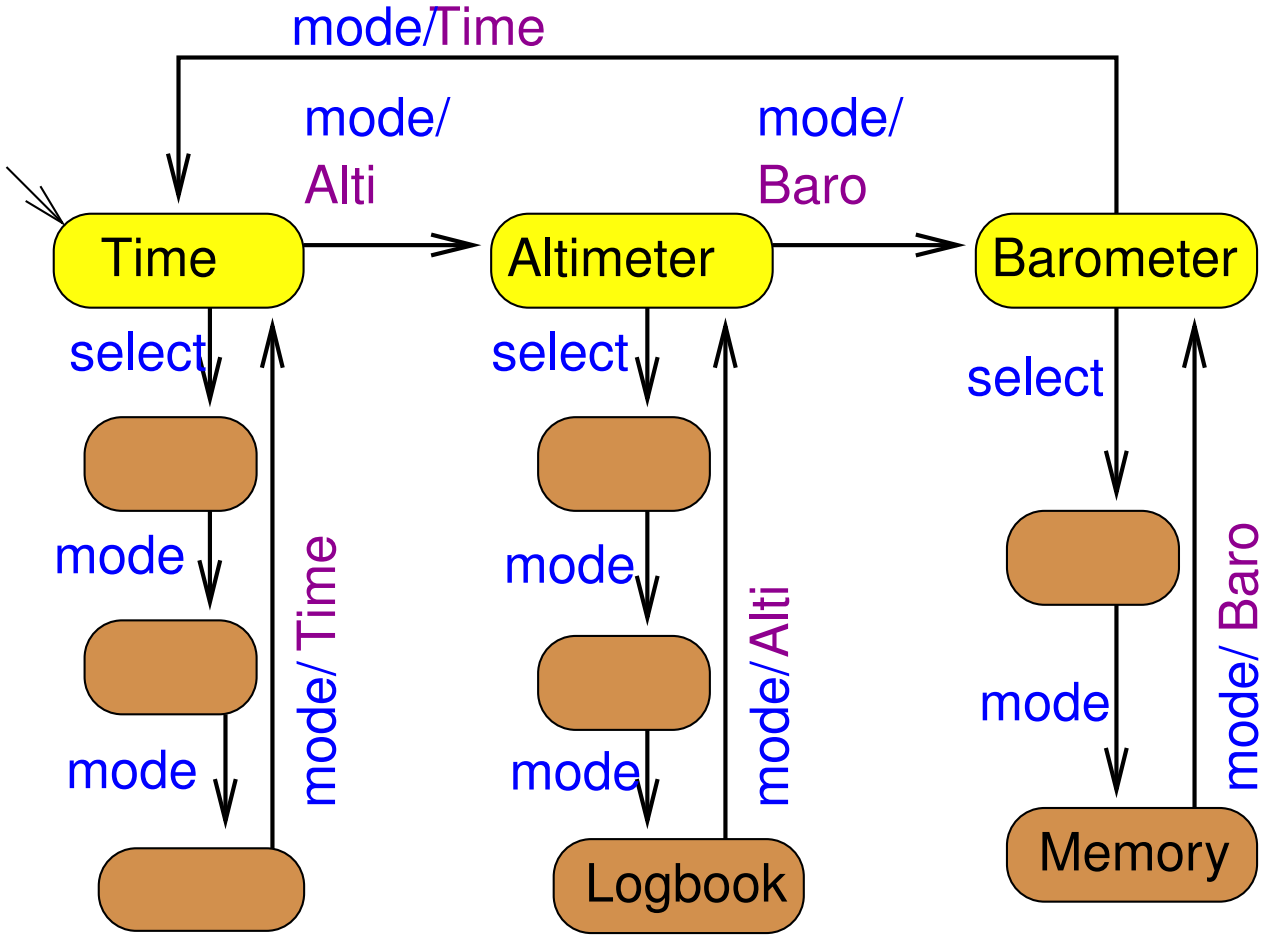
- We model interface component



- Inputs: buttons
- Outputs: signals to other components

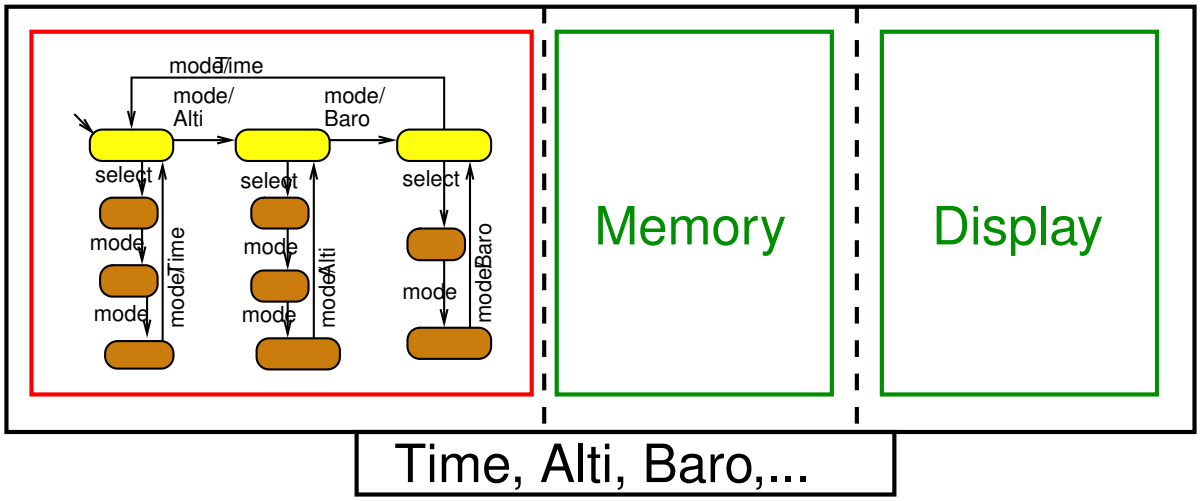


The Altimax Interface



Argos, a Synchronous Language

- Base element: Mealy automata
- Arrange modules in parallel
- Modules communicate with local signals



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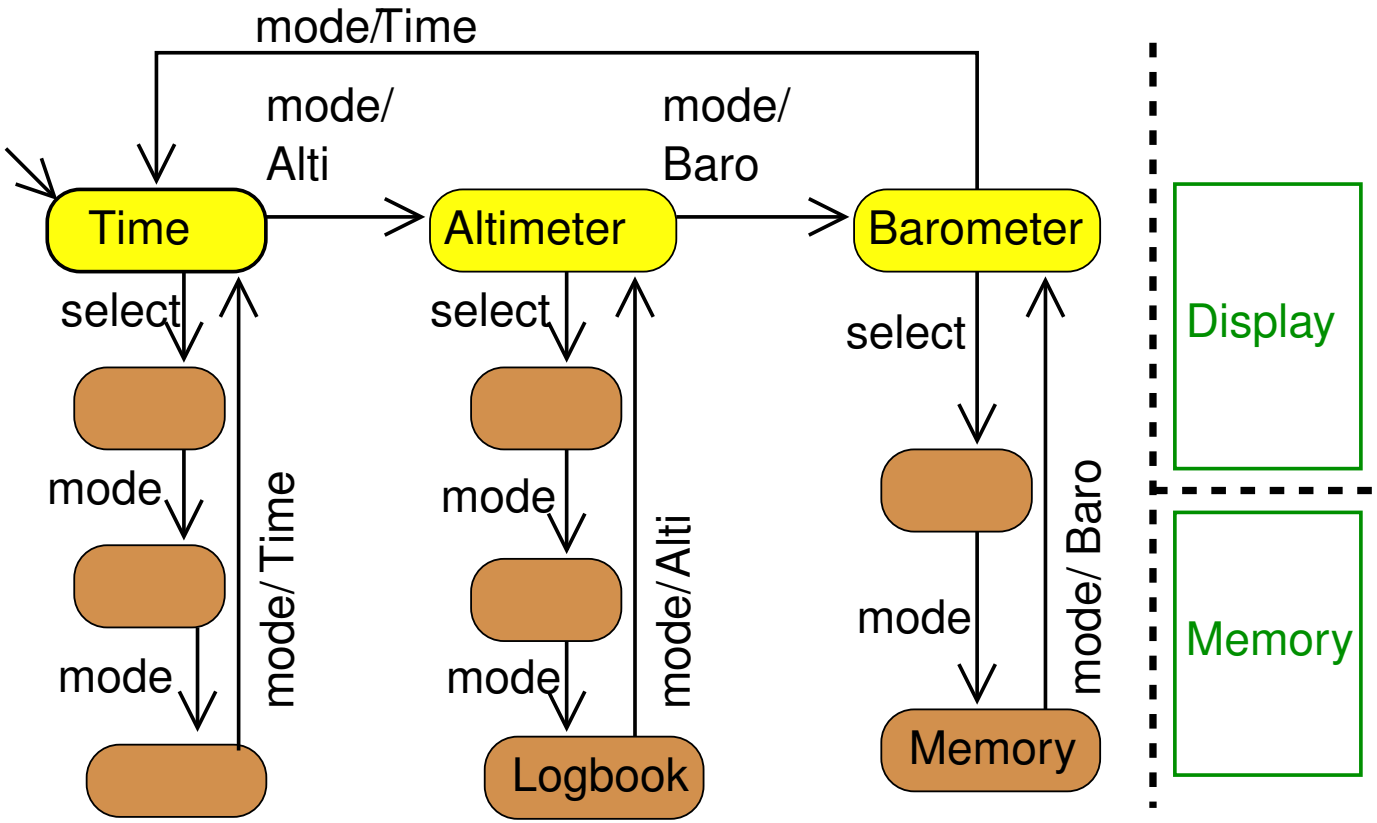

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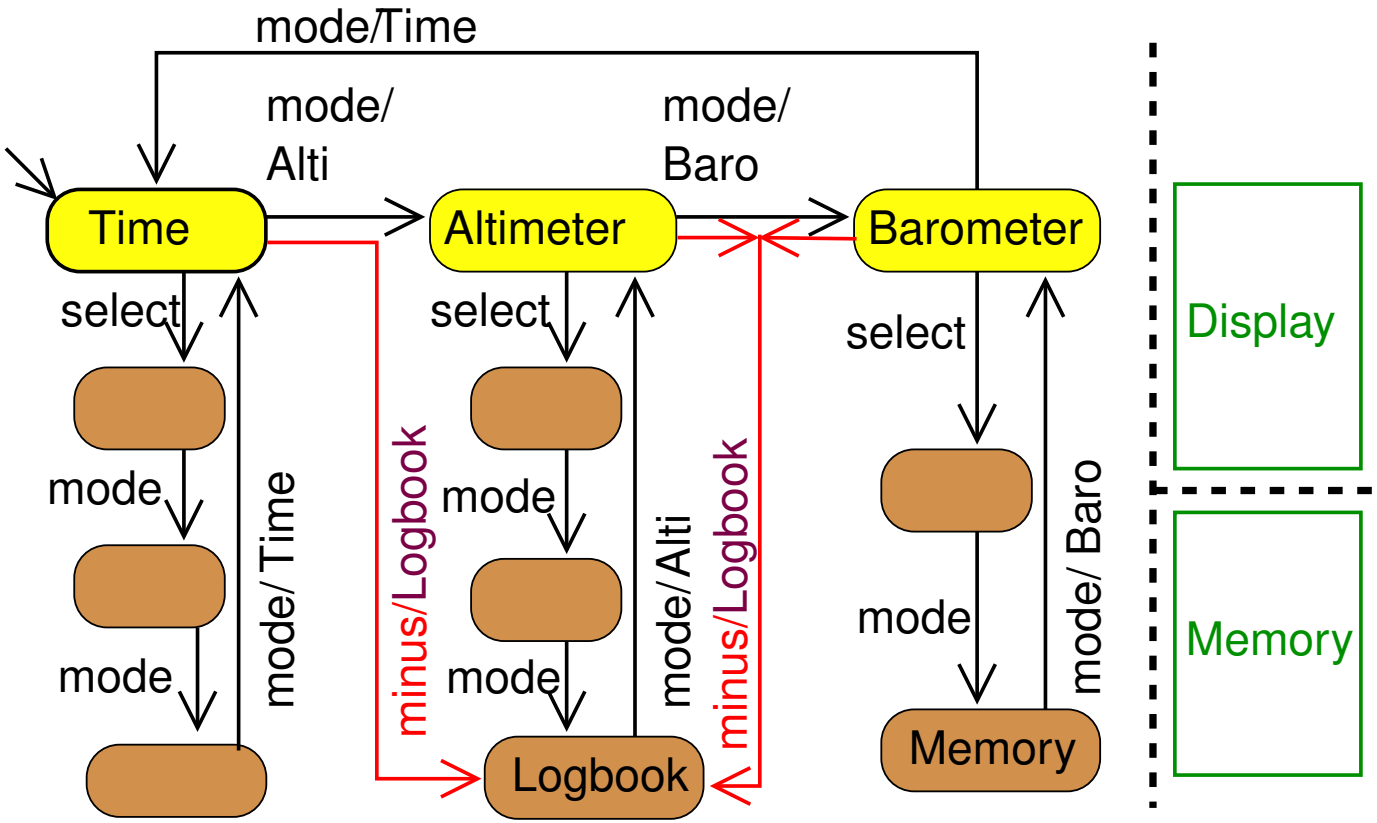
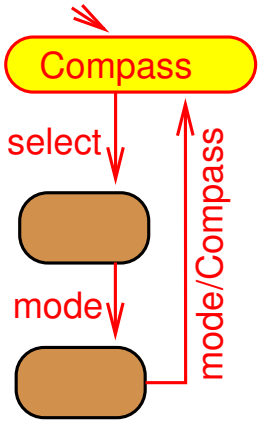
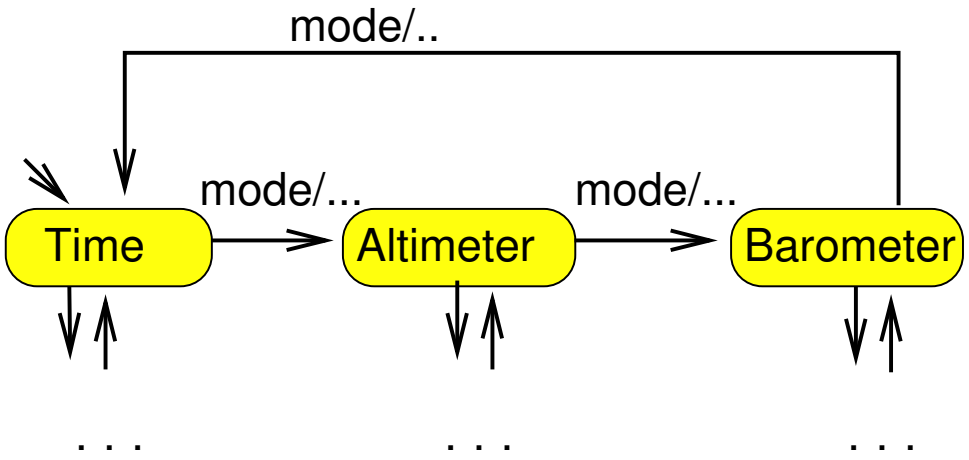
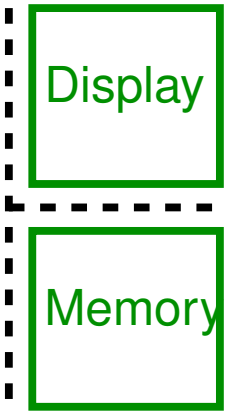


Crosscutting Concern 2: Compass Mode

- Vector model has compass mode
- Add Compass mode to Altimax base program







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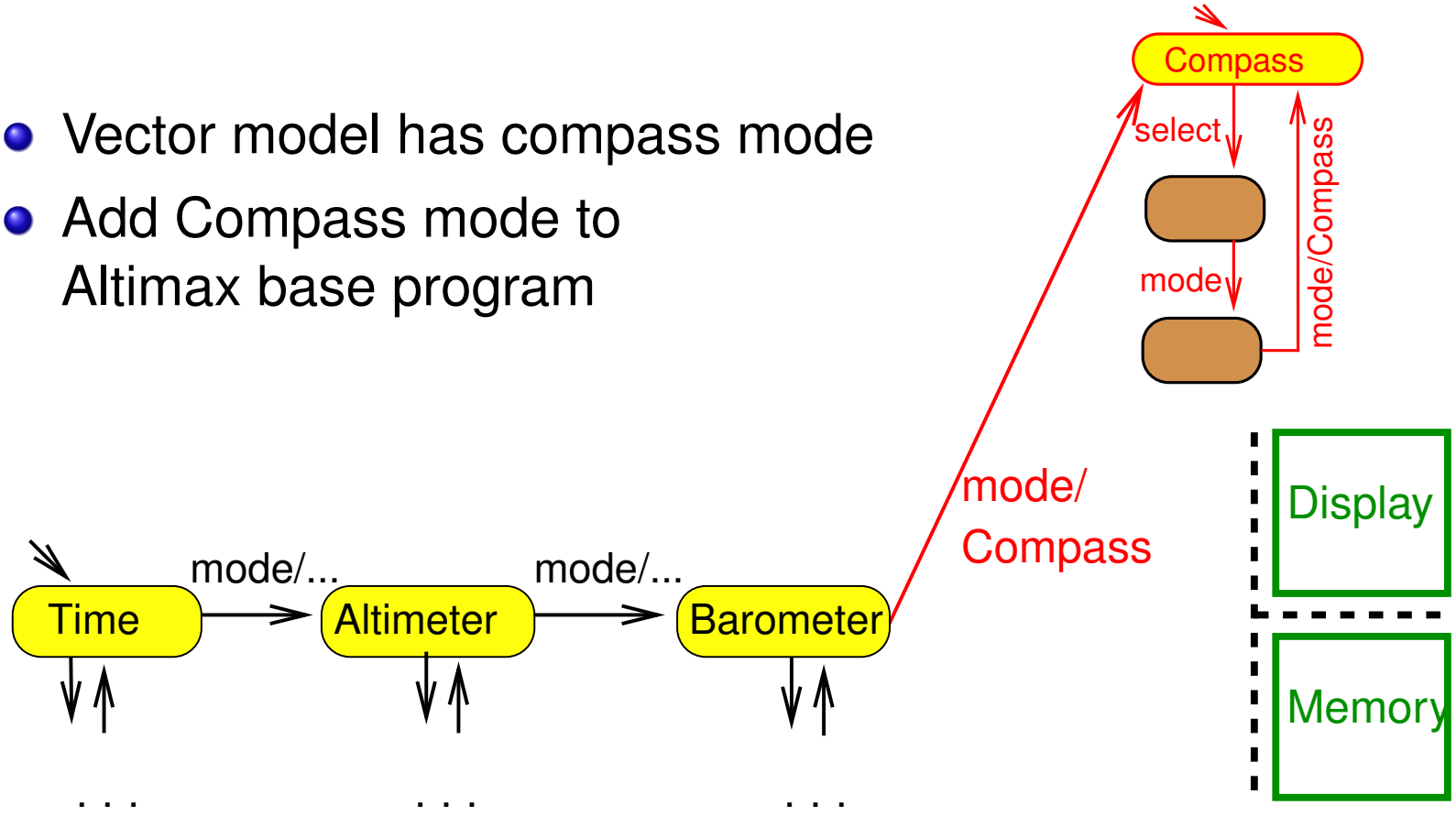

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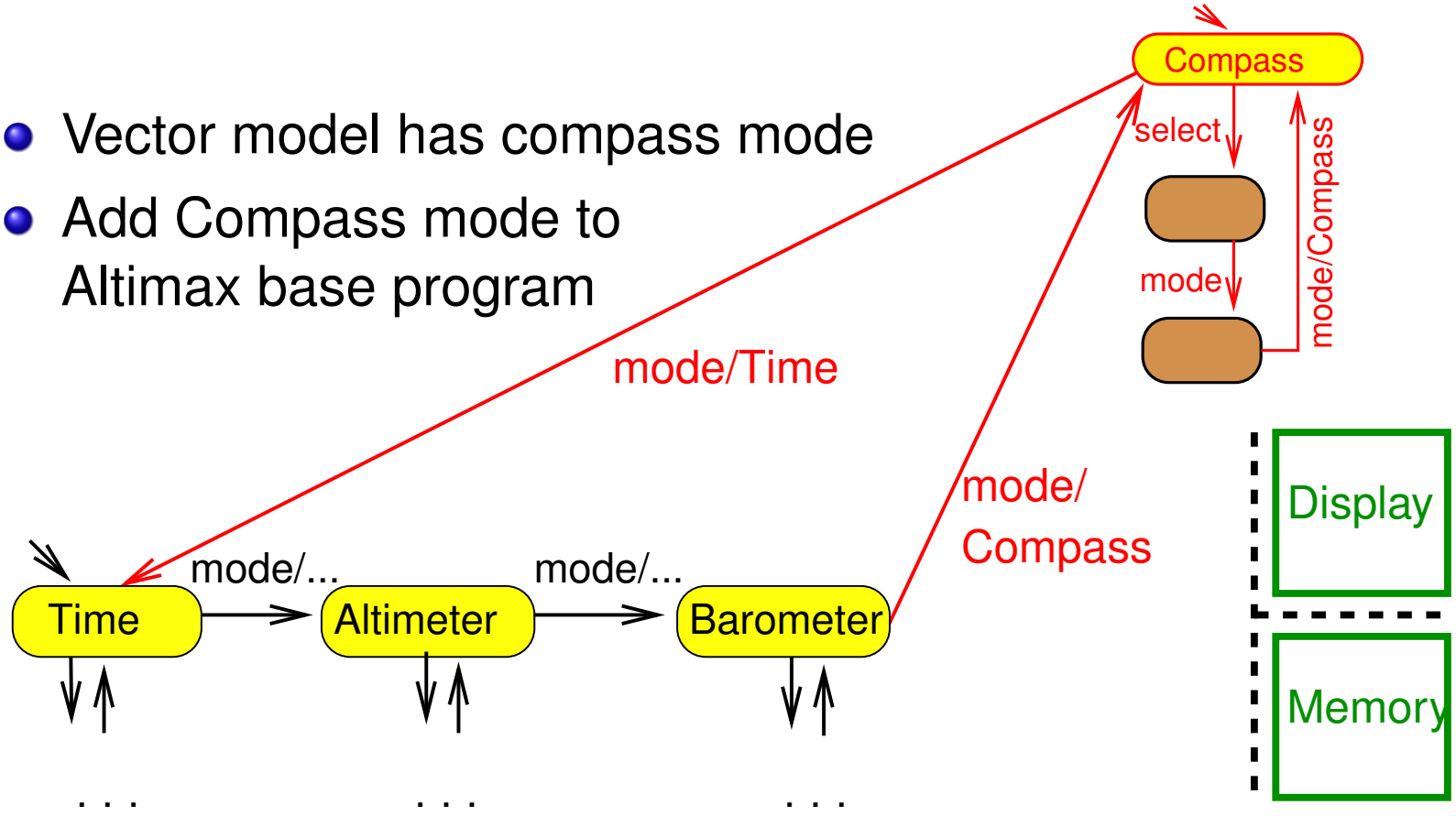


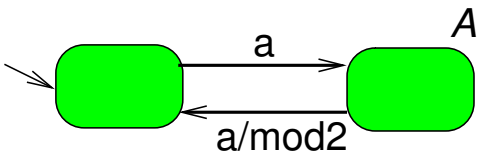
Larissa: Aspects for Argos

- Goal: aspect language for synchronous languages
- Argos adequate base language
  - simple synchronous language
  - expressive, characterizing constructs
- Must express cross-cutting concerns
- Same concepts as other aspect languages:
  join points, pointcuts, advice

Outline

Argos Operators

- Base elements: boolean signals,
  complete and deterministic Mealy automata



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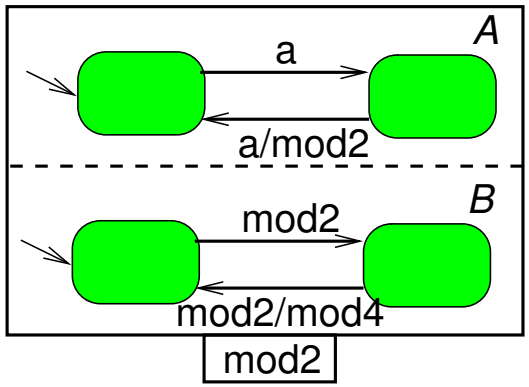

$$(A \| B) \setminus \{\text{mod2}\}$$

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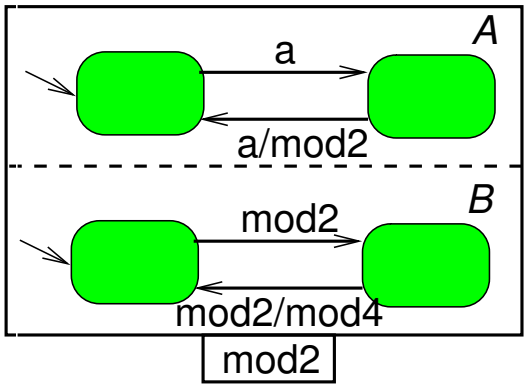
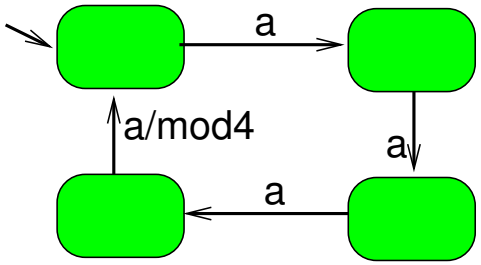
- Main operators: parallel product, local signals
- Semantics: compilation into flat automata





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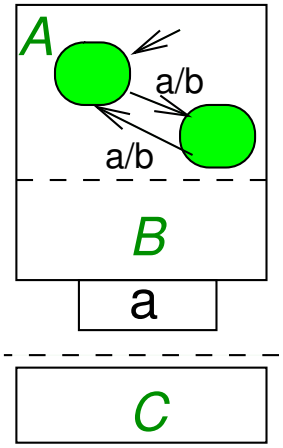
- A, B and C automata or Argos expressions



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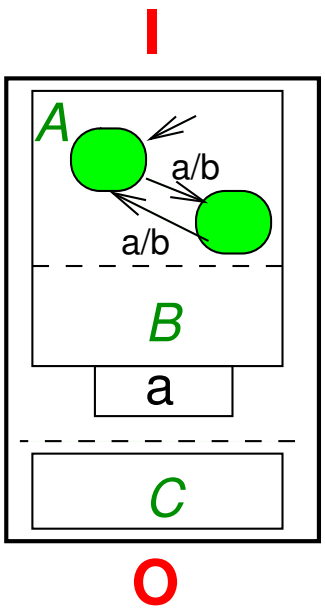

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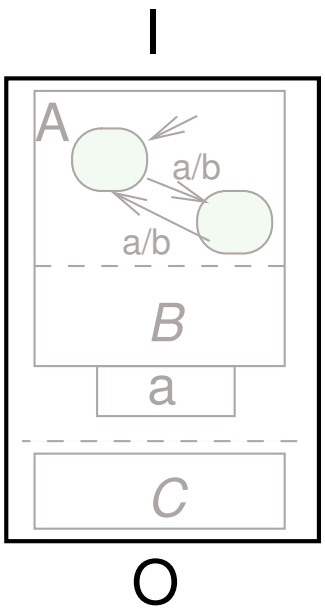

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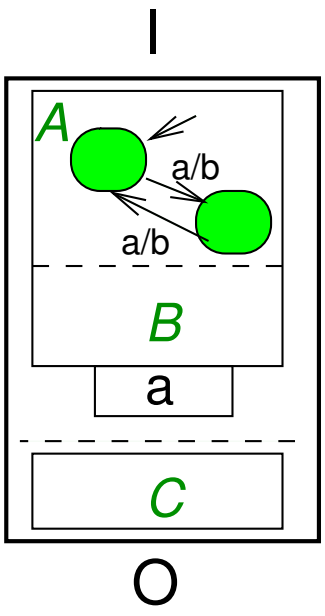

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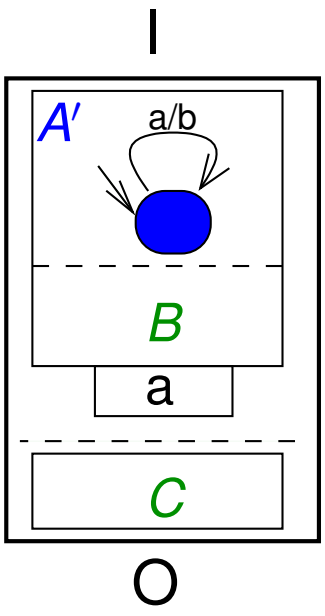

Requirements: Aspects for Argos

Express cross-cutting concerns

- crosscut structure of Argos expressions
- parallel composition can express some aspects for sequential languages

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Express cross-cutting concerns

- crosscut structure of Argos expressions
- parallel composition can express some aspects for sequential languages

Integrate well into Argos

- define as translation into automaton
- simple, formal semantics
- respect encapsulation, as other Argos operators
  - usually not respected by aspect languages

Related Work

Aspects and Parallelism

- Concurrent aspects [Douence et al, GPCE06]:
  - asynchronous base program, asynchronous execution of advice

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Aspects and Parallelism

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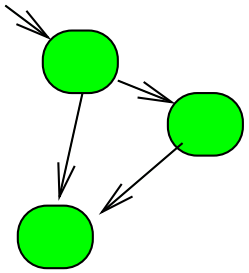
Formal Properties

- Many formalisations of aspect languages
- Aspects preserving the encapsulation:
  - Composition Filters [Bergmans, Aksit]: intercept and modify messages between components
  - Open Modules [Aldrich, ECOOP06]: add additional information to interface

Larissa

- Join points: one step in the execution
- I.e., transitions in an automaton



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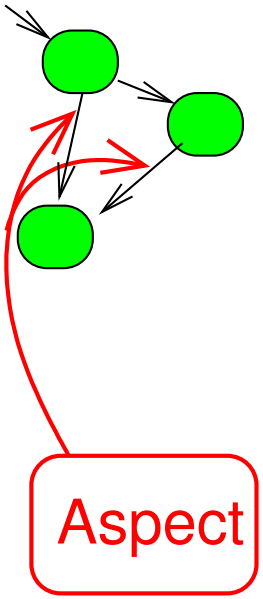

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- Advice: modify transitions
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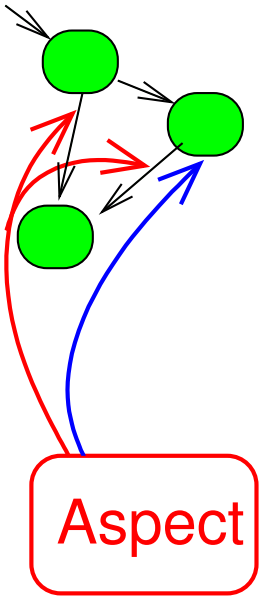

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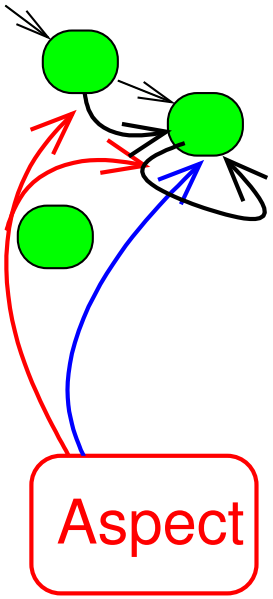

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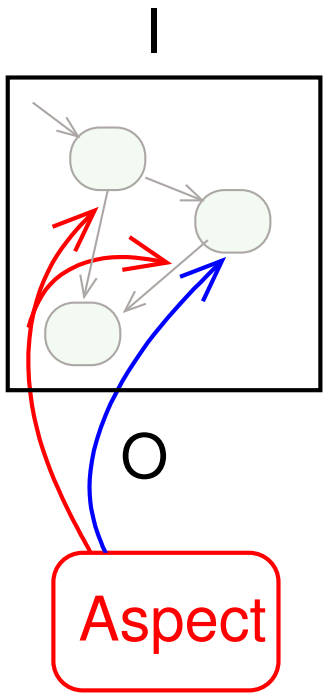

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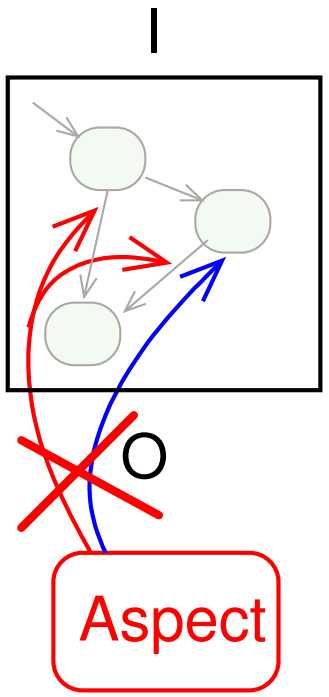

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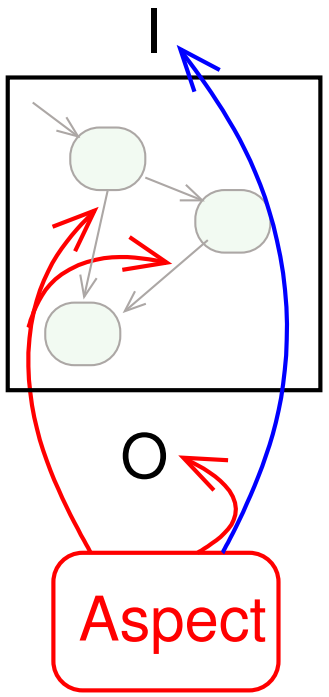
  - aspect must only refer to interface



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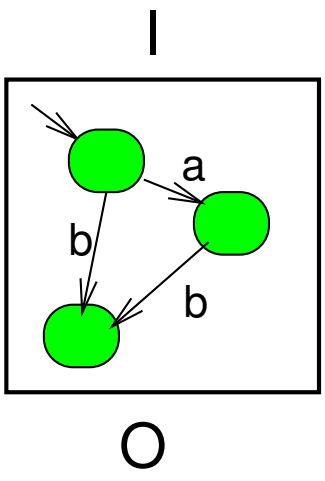

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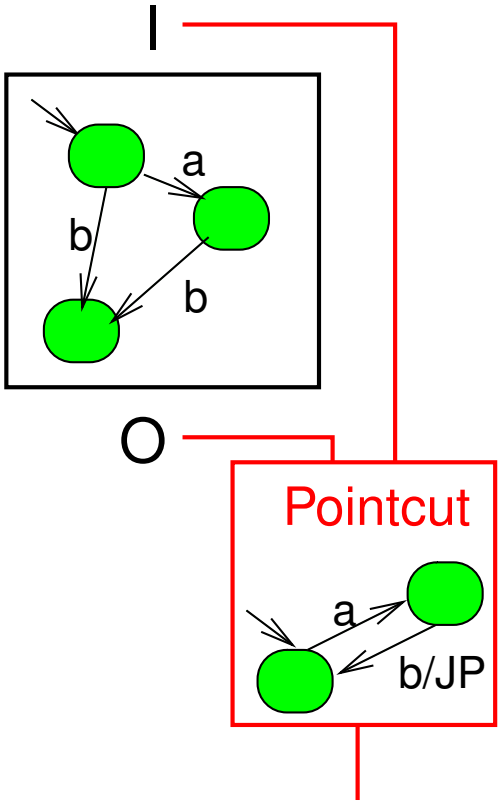

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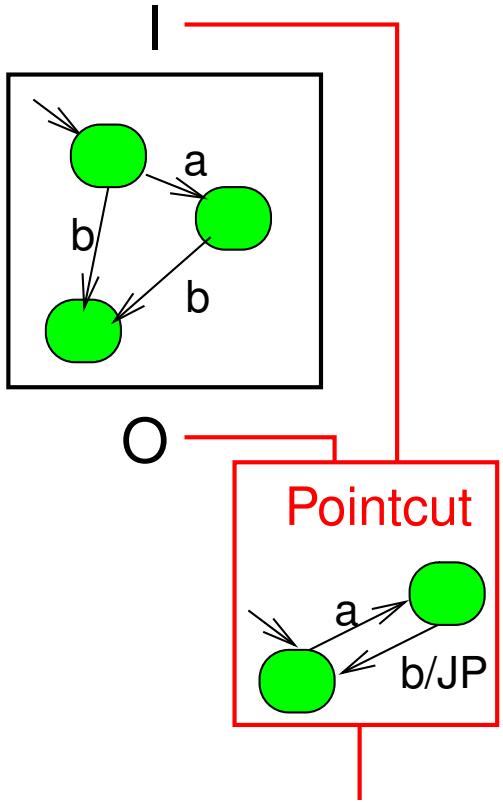

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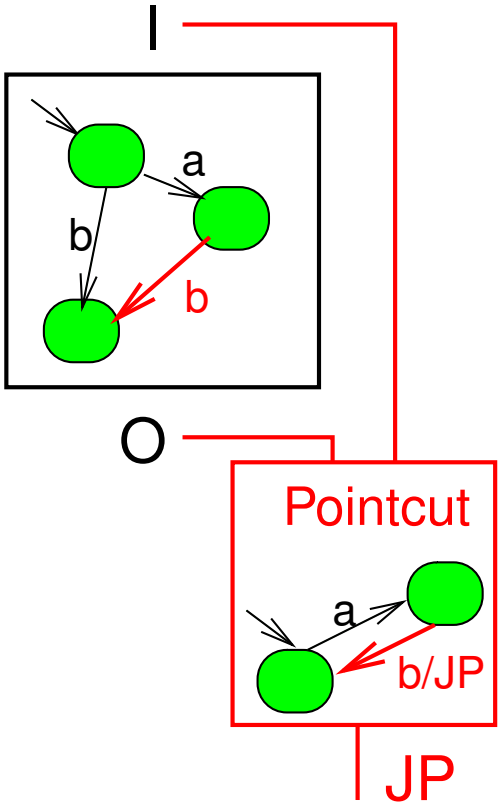

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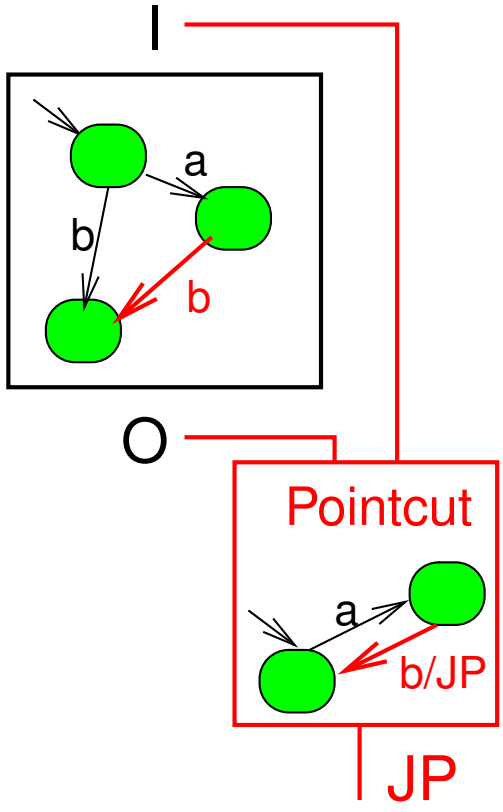
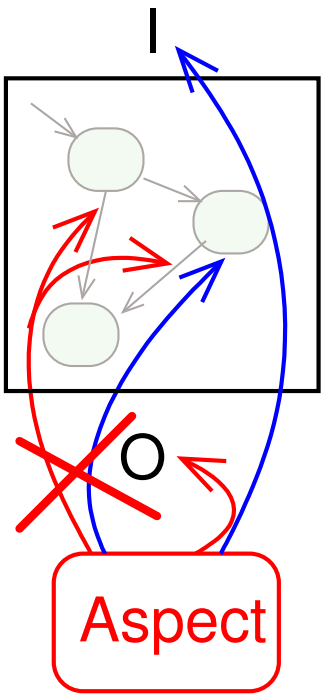
- Transitions identified statically by parallel product



Advice

- Difficulty: specify one new target state



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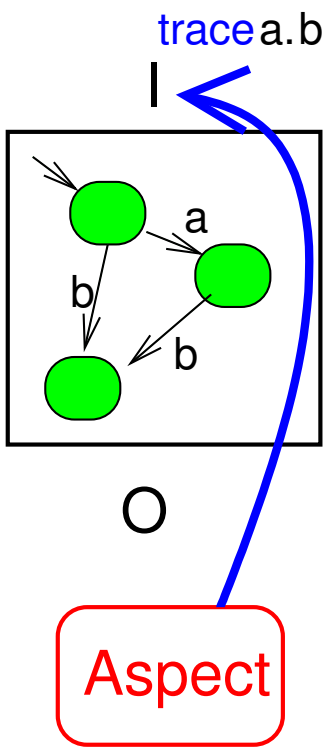

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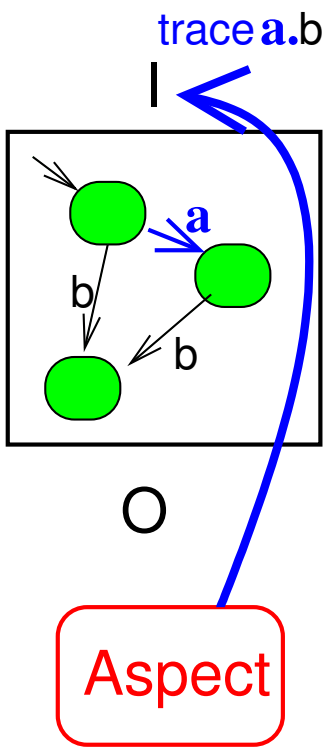

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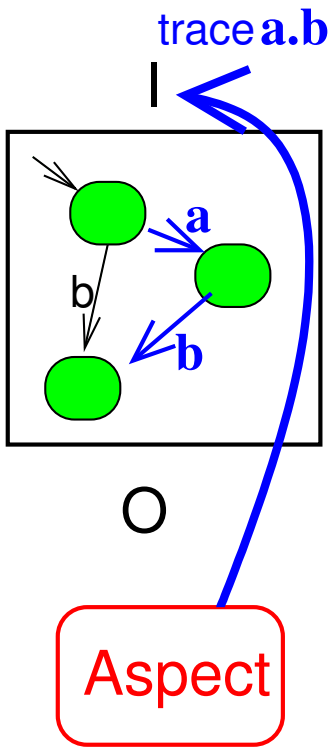

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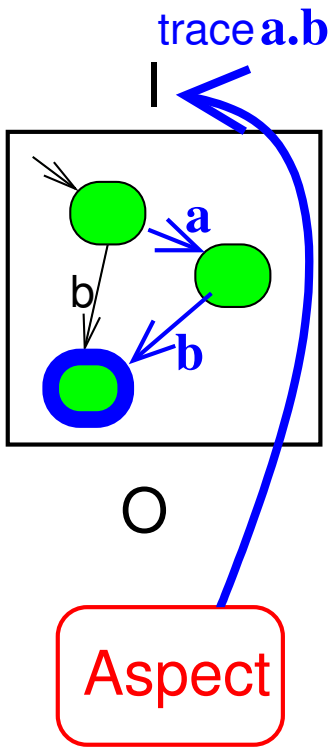
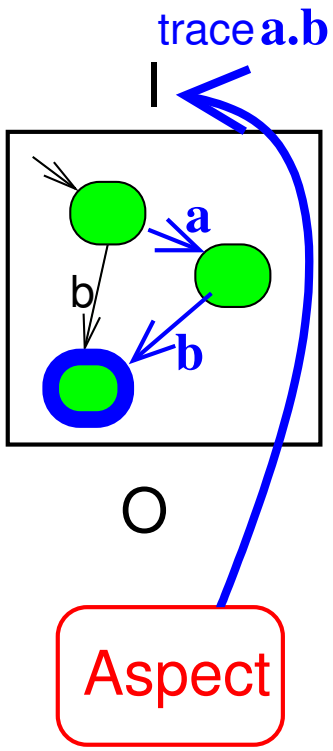


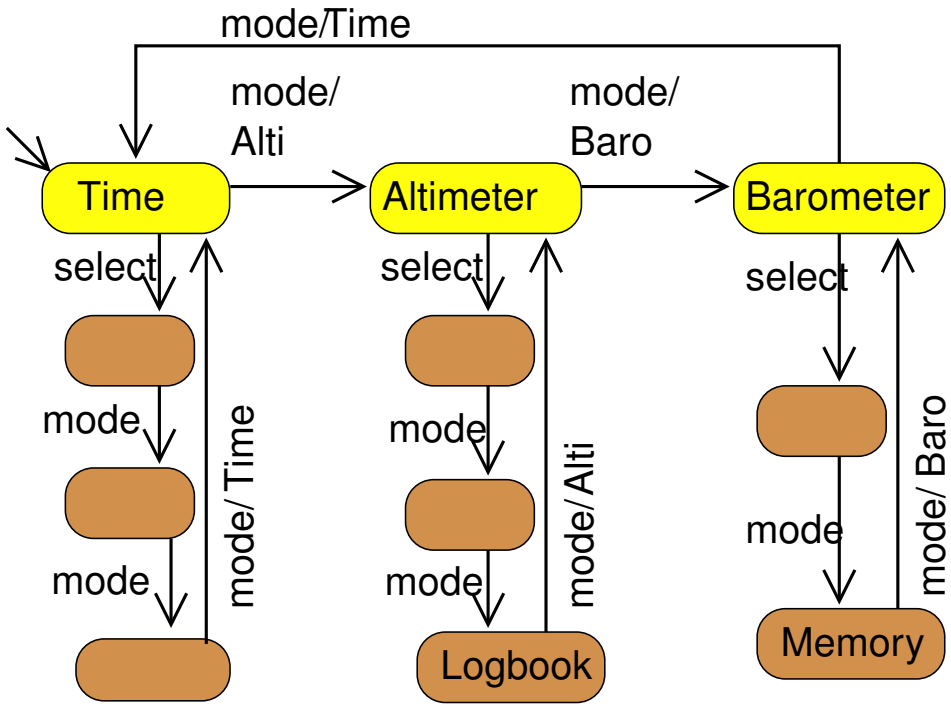
Advice

- Difficulty: specify one new target state
- Solution: execute finite input trace
  - automaton deterministic, thus always identifies one state
- Two kinds:
  - toInit advice: execute trace from initial state
  - toCurrent advice: execute trace from source state of transition



Example: Logbook Shortcut Aspect LB

- Pointcut: transitions in main modes where minus is true
- Advice: trace mode.select.mode.mode, output Logbook



altimax

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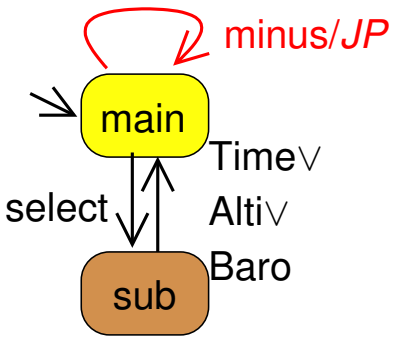
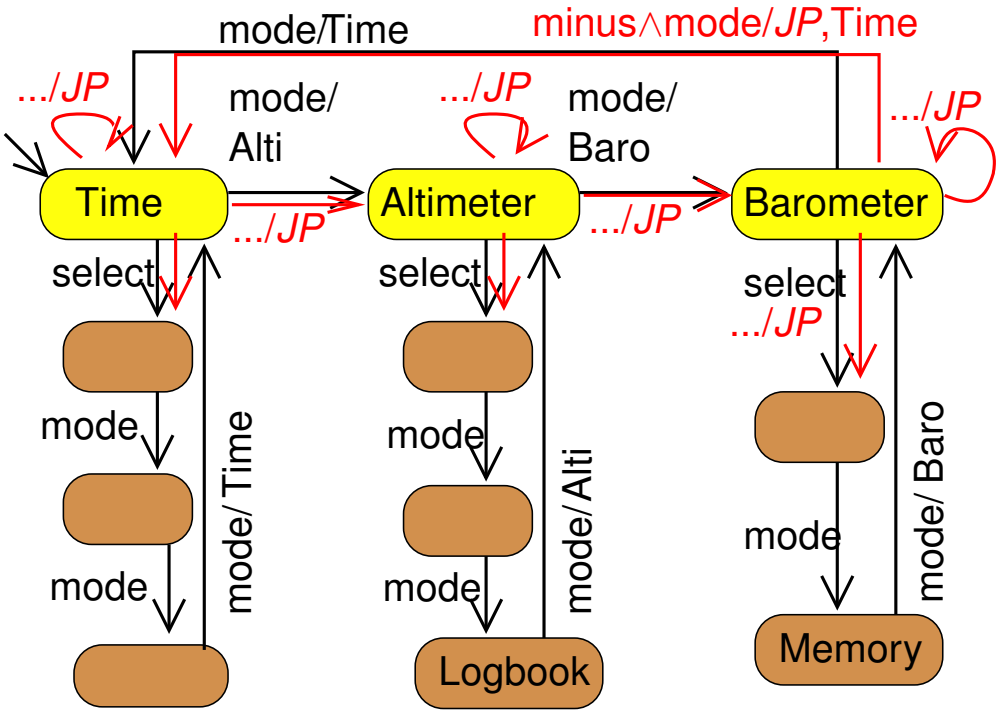


pointcut of LB



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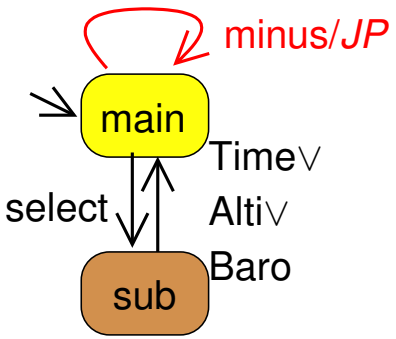

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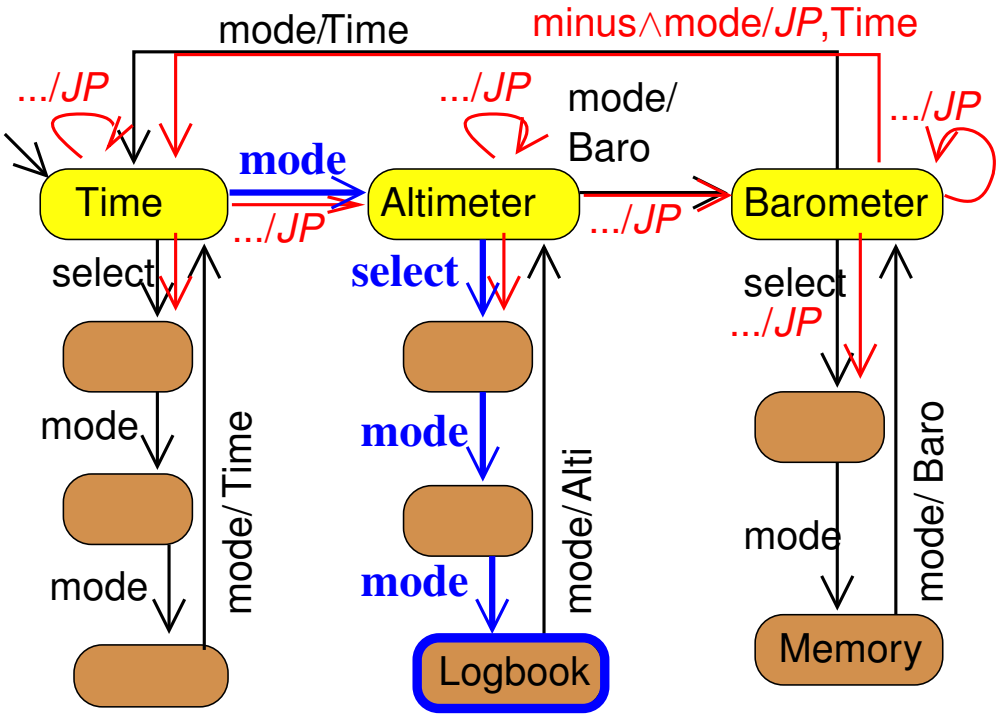

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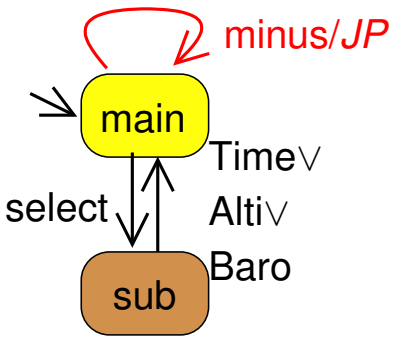

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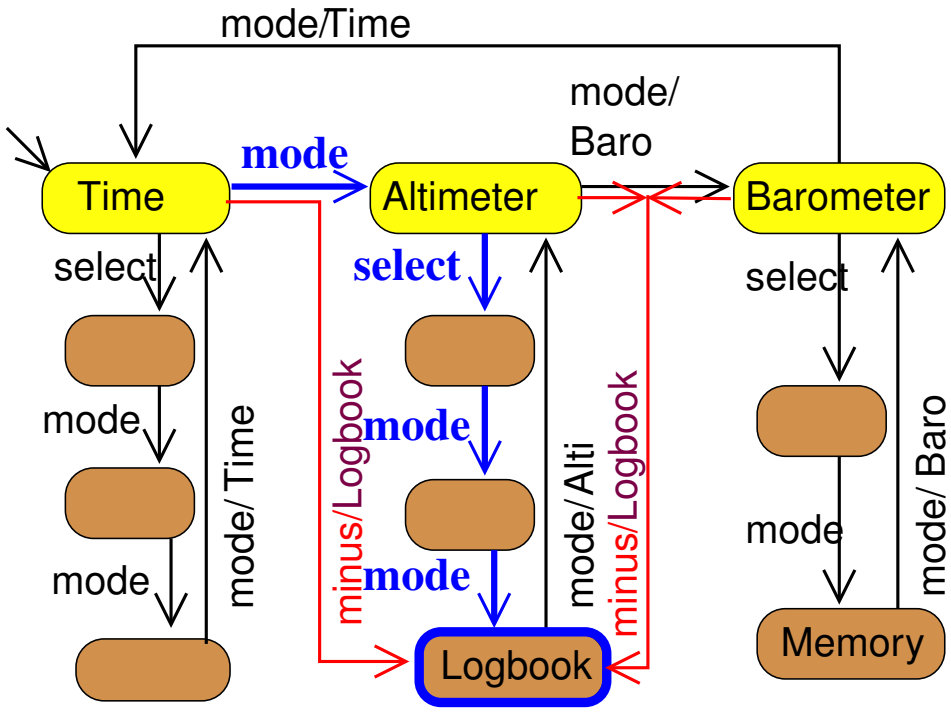
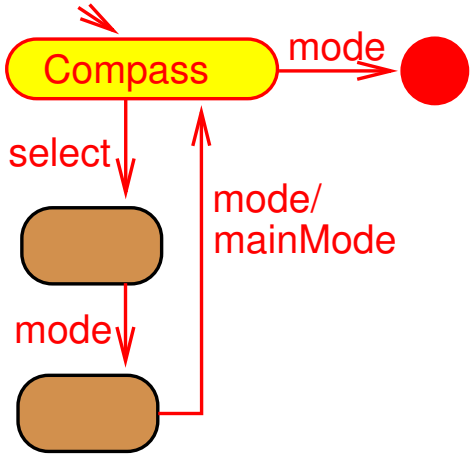


altimax◁LB

Advice Program

- Advice insufficient for Compass Concern
- Replace transition by advice program
- Advice program has terminating state: represents return to base program



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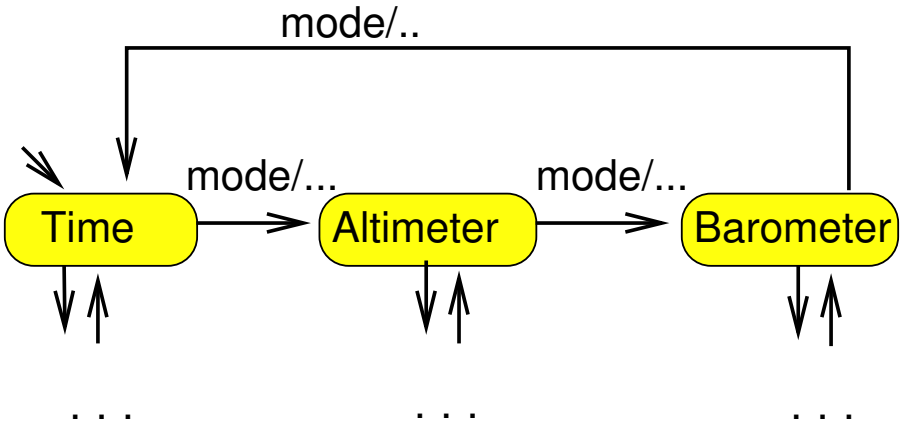

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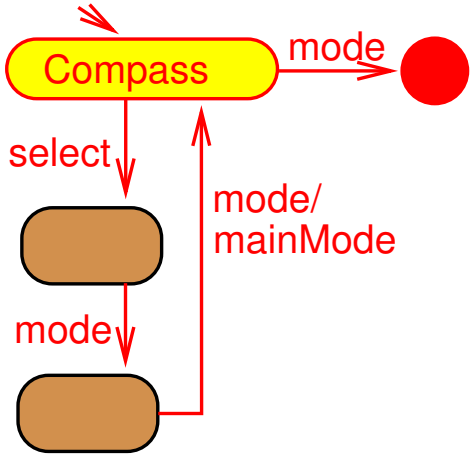

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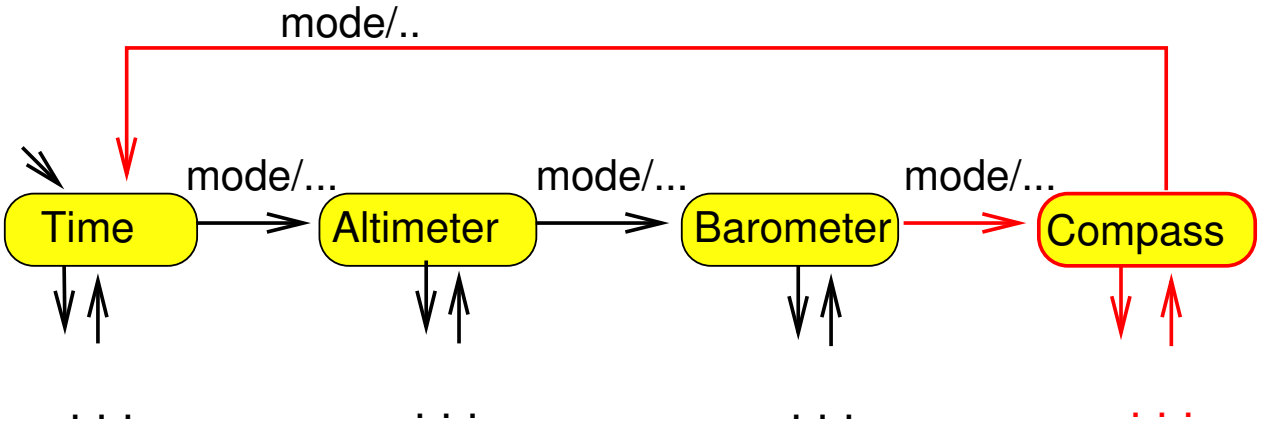

altimax ◁compass

Recovery Advice and Compiler

Recovery advice

- “Jumping backward”
- Identify set of recovery states
- Jump to last recovery state that was passed

Recovery Advice and Compiler

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Compiler for Argos and Larissa

- All language variants implemented
- Experimentation with many examples
- Written in Java, AspectJ, BDD library
- Available at

`http://www-verimag.imag.fr/~stauch/ArgosCompiler/`

Outline

Formal Analysis Tools

- Larissa: small language, formally defined, with simple semantics
- Well adapted to study formal properties of aspect languages
- We studied two such properties:
  - interaction of several aspects
  - combination of Larissa with contracts

Aspect Interaction

Aspect Interaction

- Do several aspects influence each other?
- When is $P \triangleleft A1 \triangleleft A2 \sim P \triangleleft A2 \triangleleft A1$?

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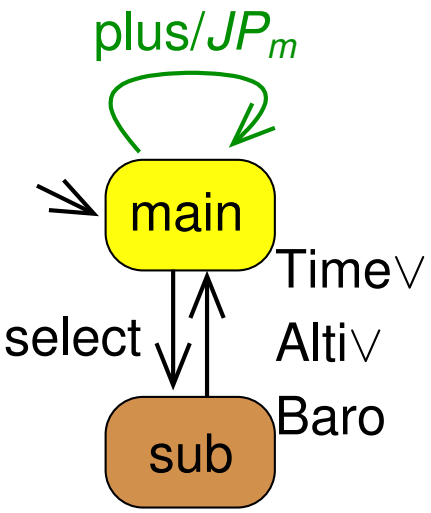
Example: Second Shortcut Aspect M

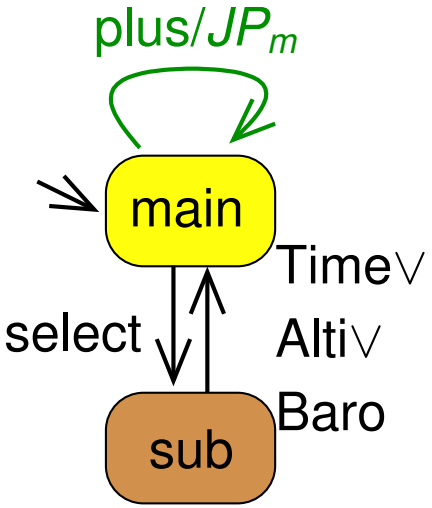
- Also use plus button as shortcut in the main modes
- Pressing plus goes to the Memory mode



Pointcut of M

Weaving the Second Shortcut Aspect

- Weave M into altimax◁LB



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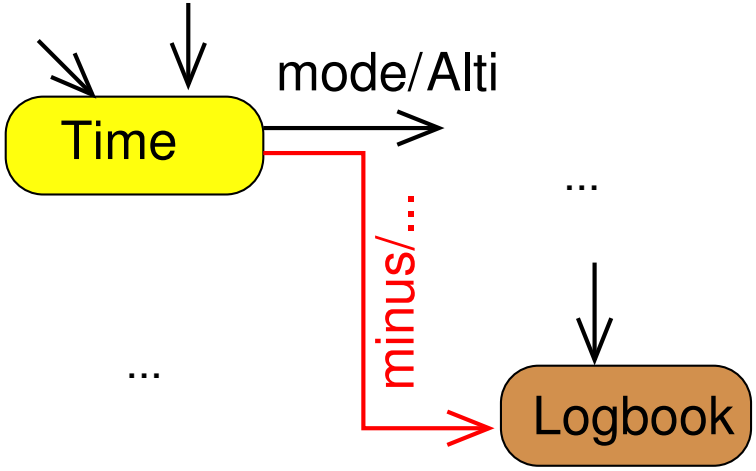
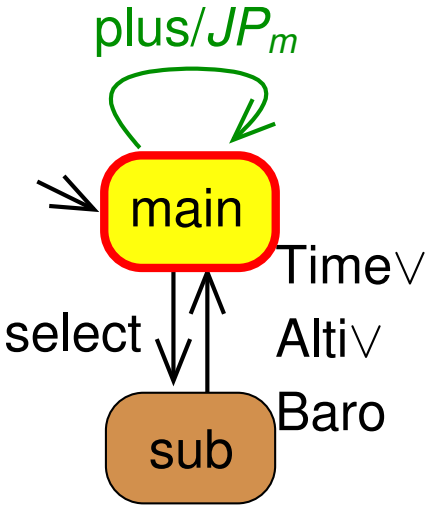


altimax◁LB

Weaving the Second Shortcut Aspect

- Weave M into altimax◁LB
- When pressing minus in main mode:
  - altimax◁LB goes to submode
  - pointcut stays in main mode



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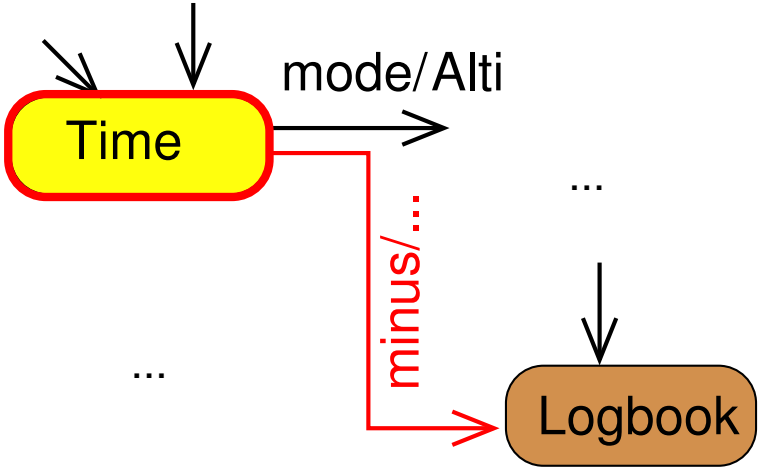

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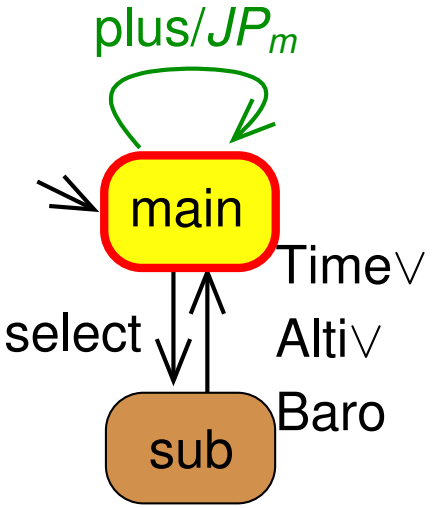

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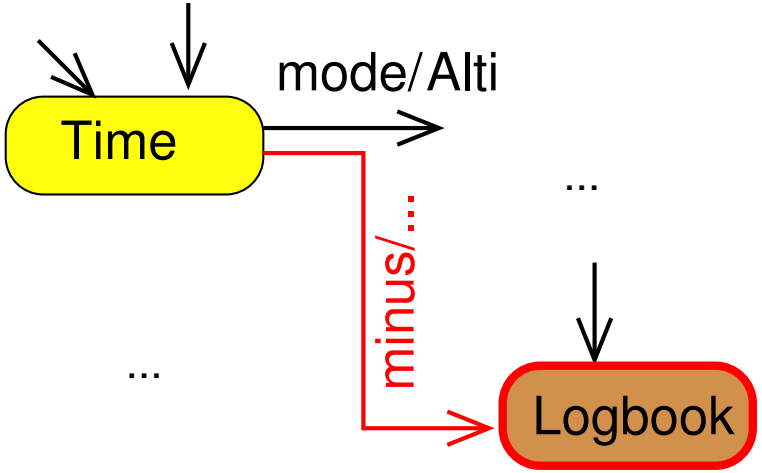

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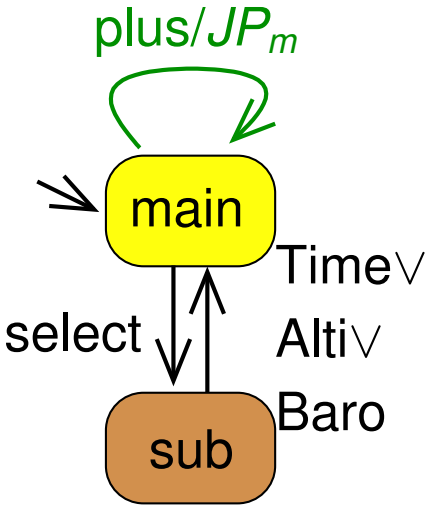

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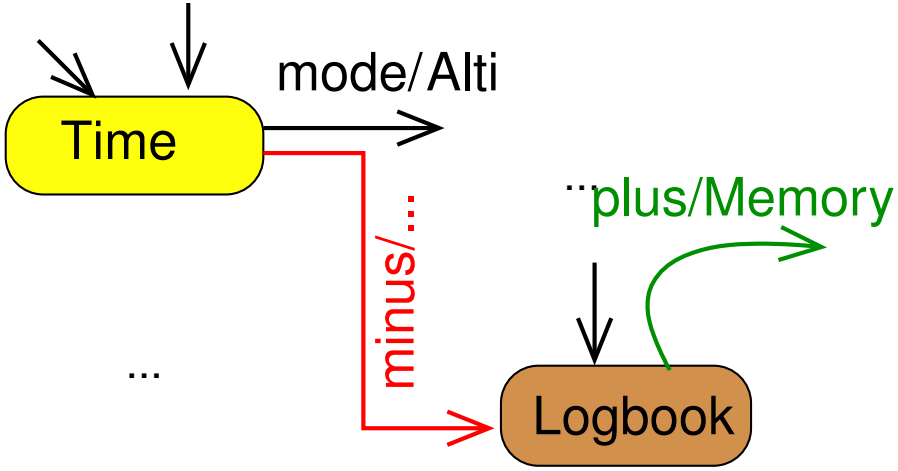

altimax◁LB◁M

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- Idea: weave aspects jointly into the program

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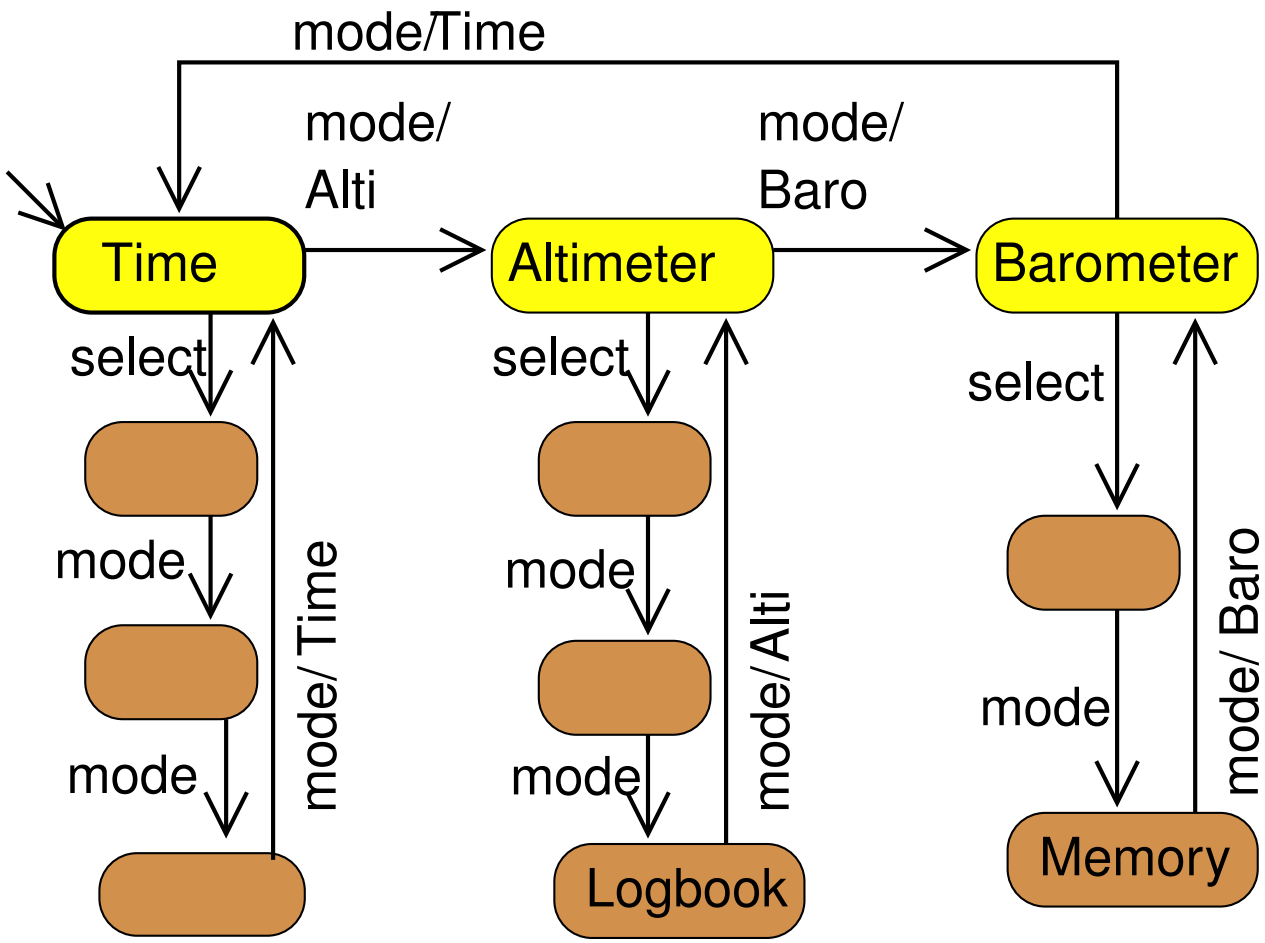
- Select join points for all aspects first, then apply advice

Joint Weaving: altimax◁(LB,M)

1. apply pointcuts and determine join point transitions
2. sequentially apply advice

Application to the Example: altimax◁(LB,M)



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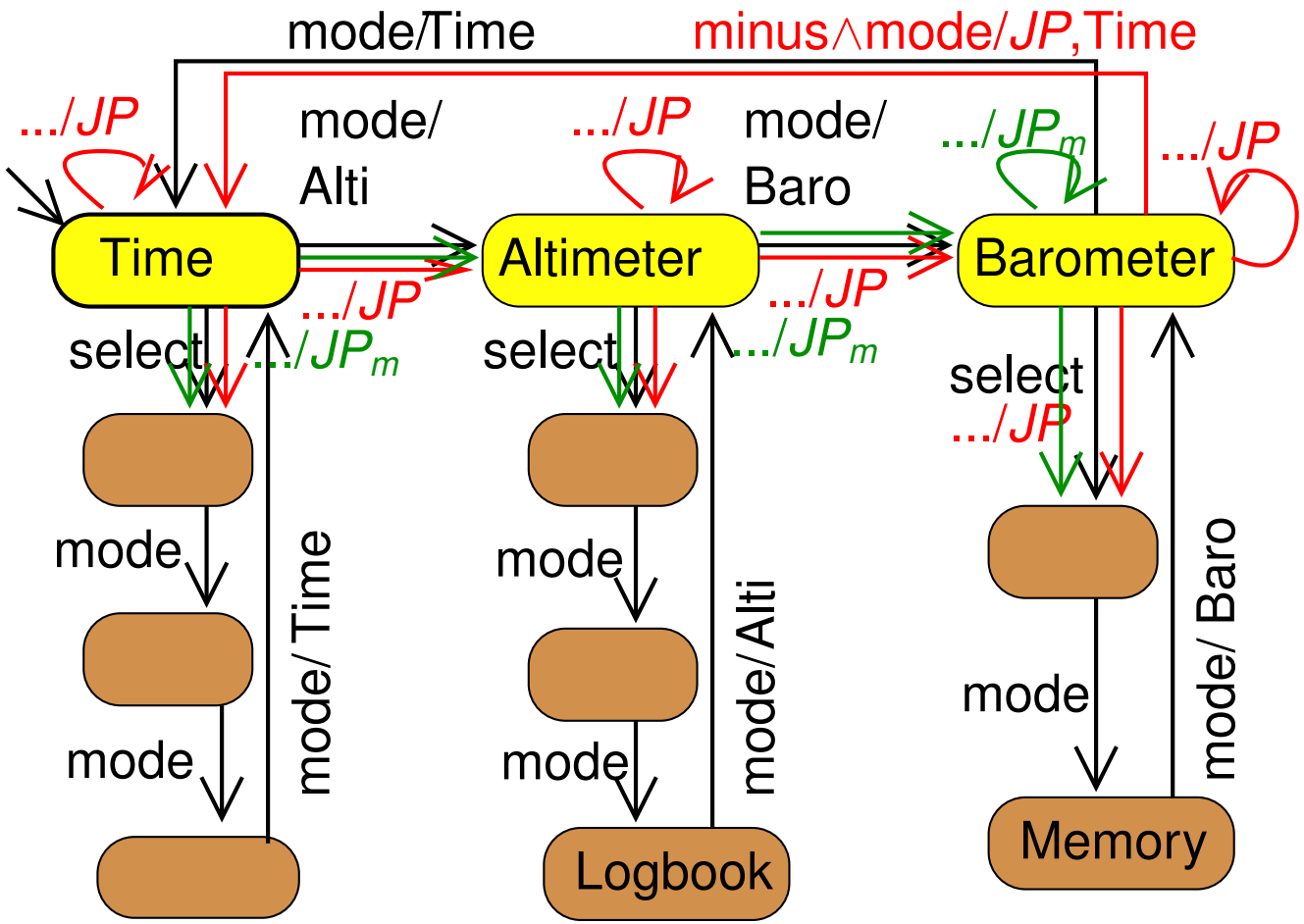

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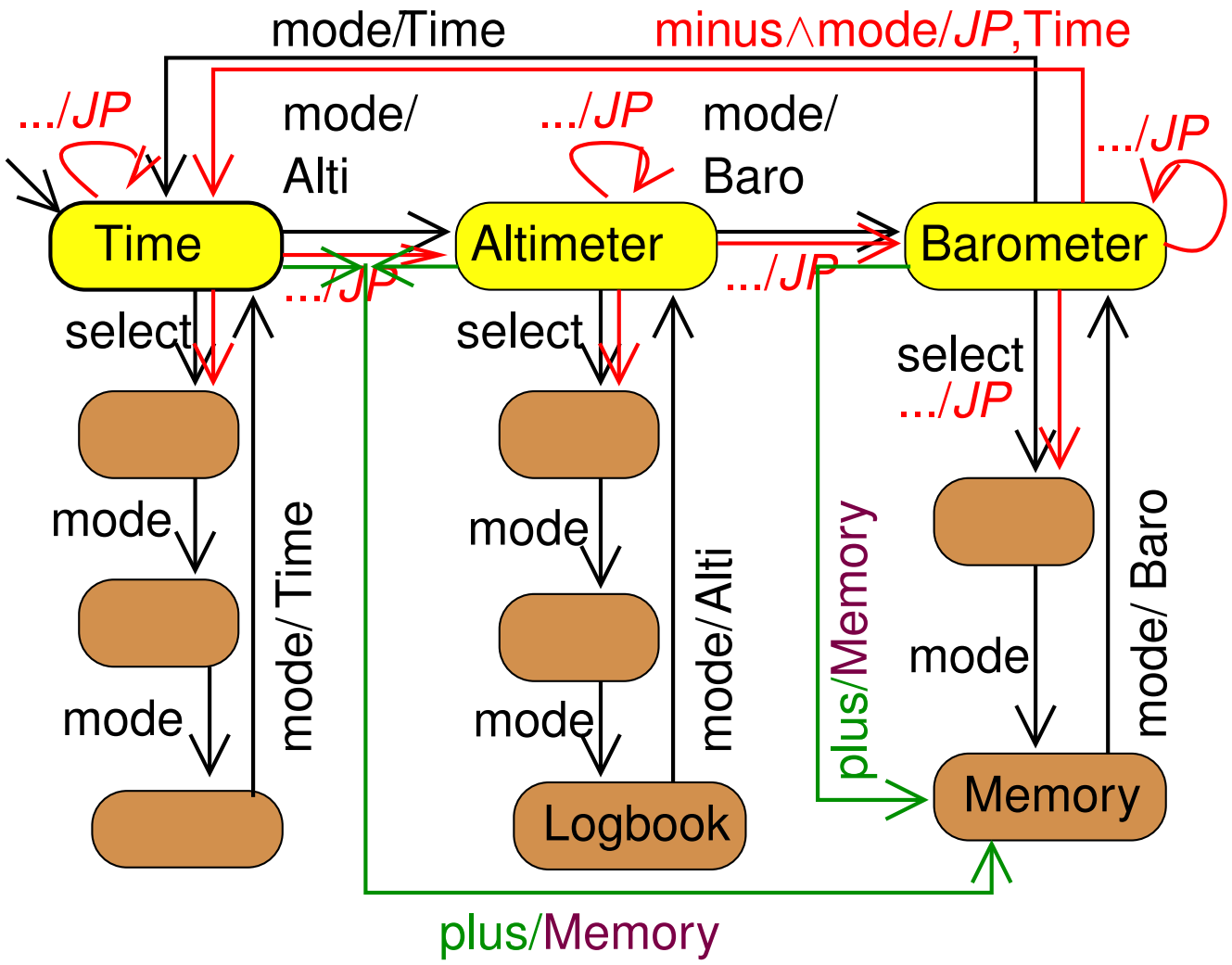

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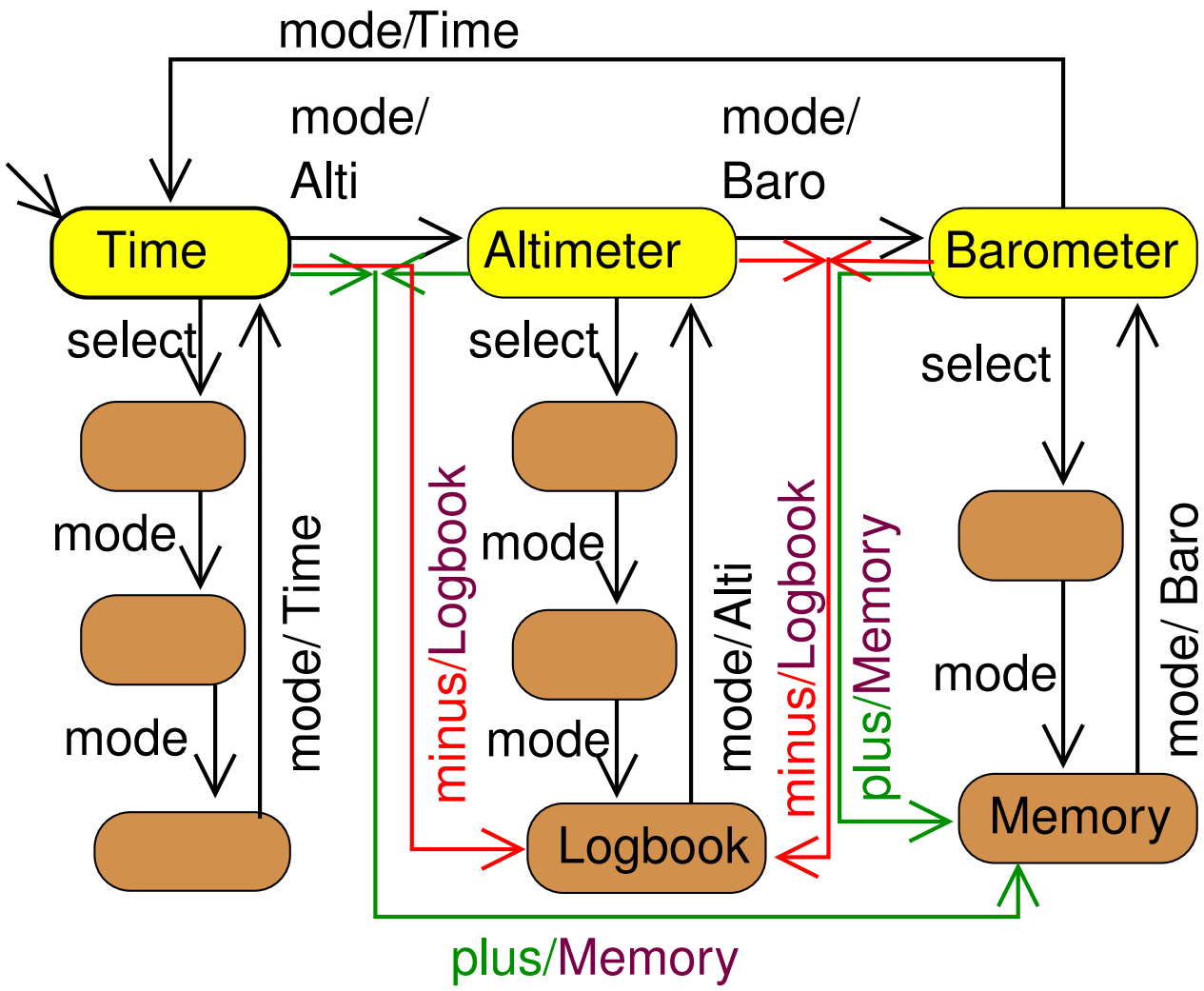

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Theorem for Jointly-Woven Aspects

- Noninterference of two aspects, for any base program:
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- Noninterference of two aspects, for given base program P:
  - if no transition selected by both aspects
    in product of pointcuts and P

Design-by-Contract

- Originally introduced by Bertrand Meyer for object-oriented programming
- Contract: assumption $A \Rightarrow$ guarantee G

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- Example (in Java):

```
class C{
  /* @ assume i < 10 */
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   int m(int i ){...}
}
```
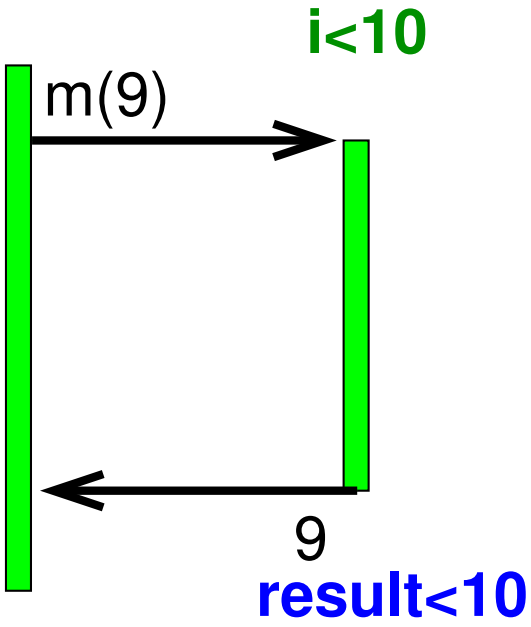

Aspects Modify Contracts

- Example call to m: i=9, returns 9



Aspects Modify Contracts

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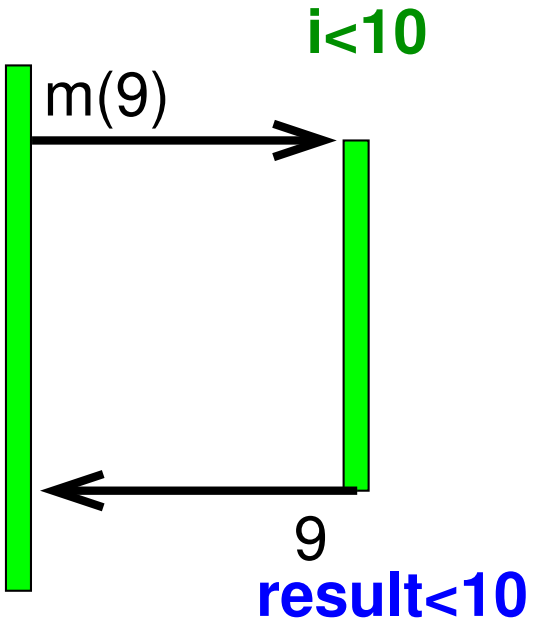

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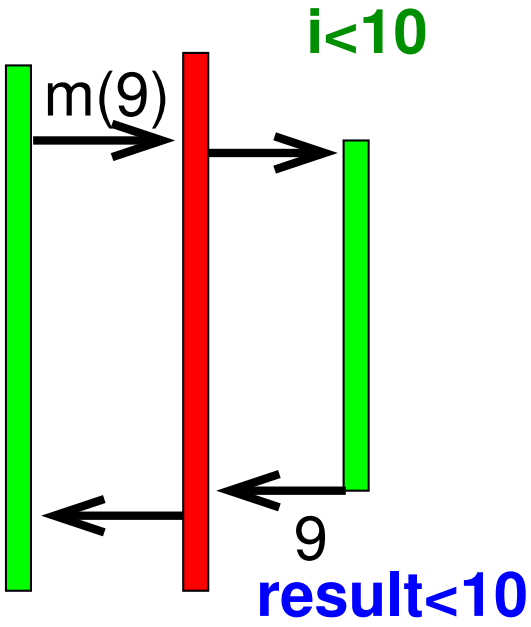

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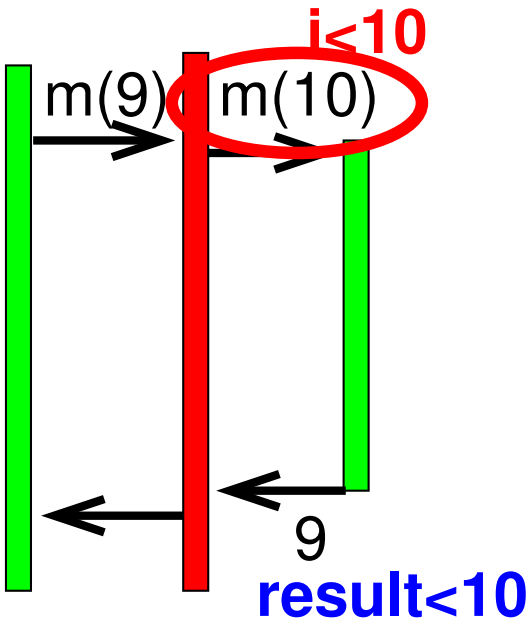

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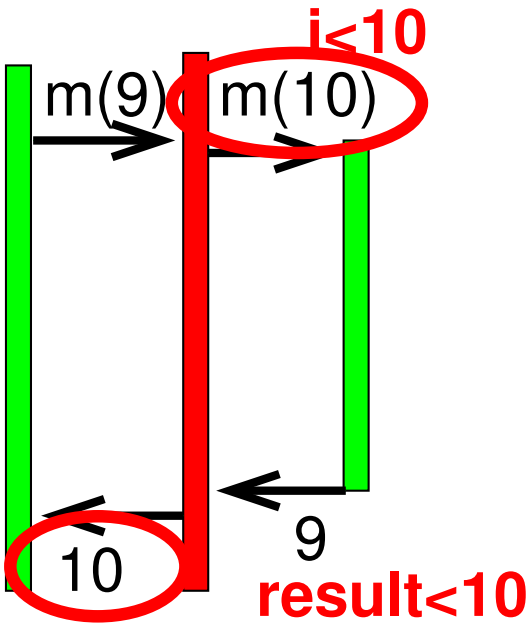

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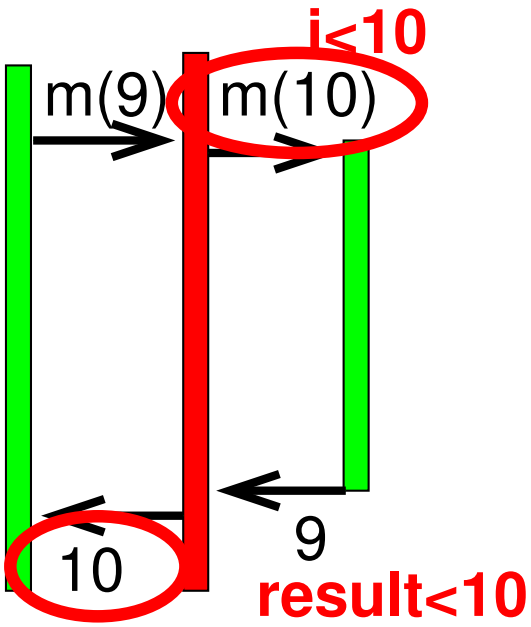

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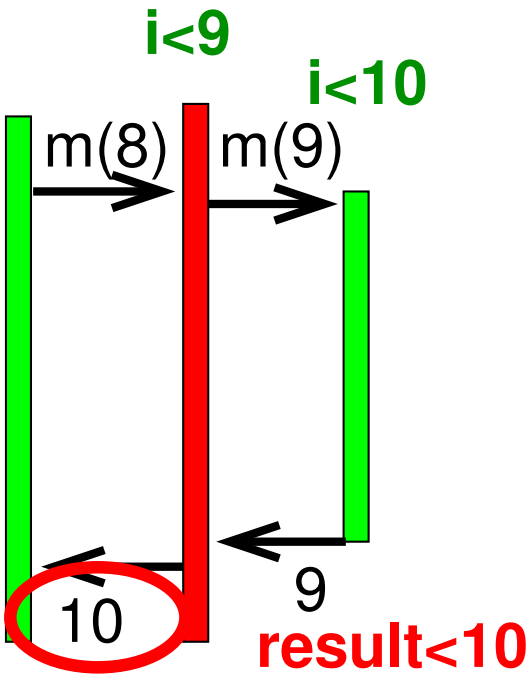

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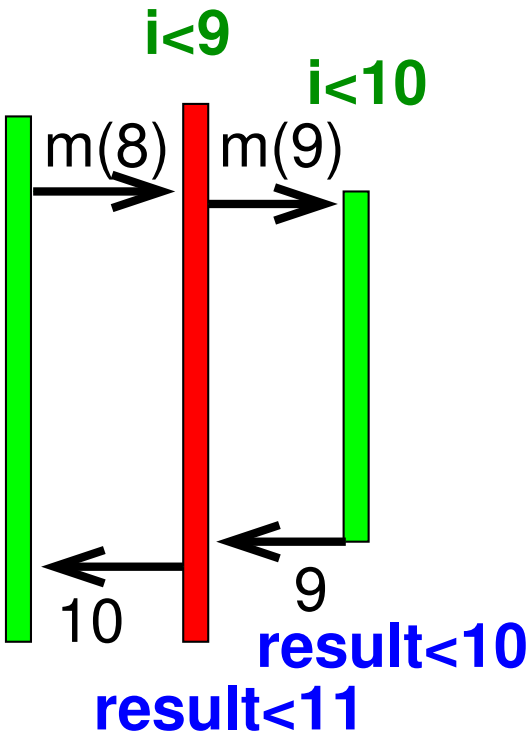

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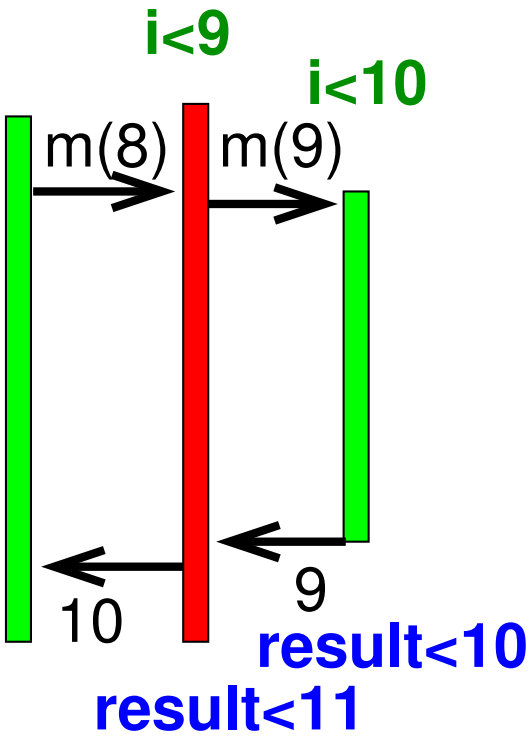
- Idea: derive new contracts automatically



Contracts for Reactive Systems

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- Example with input a and output b:
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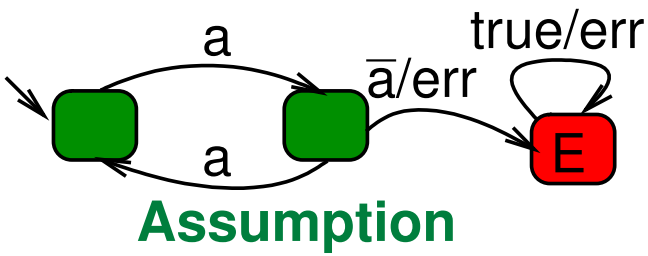
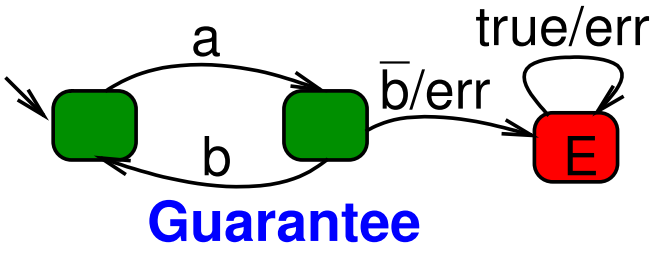
- Observers can express such properties
- Inputs are accepted until output err is emitted





Generating New Contracts

- Goal: apply *asp* to (A, G), and obtain (A', G'), such that

$$P \models (A, G) \Rightarrow P \triangleleft asp \models (A', G')$$

- Idea: Simulate the effect of the aspect on the program as far as possible on A and G
- Done for Argos and Larissa aspects
- Advantages of the approach:
  - determine effect of the aspect on program before it is written
  - allows modular verification

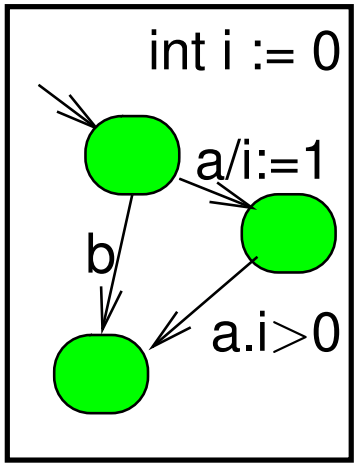
Outline

Contributions

- Contributions:
  - Identification of cross-cutting concerns in reactive systems
  - Larissa, an aspect language for Argos
    - formal definition and properties, preservation of equivalence
    - developed many examples and case studies
  - Formal analysis tools for Larissa
    - Non-Interference
    - Combination with Design-by-Contract
  - Compiler for Larissa
    - implements all language variants
    - handles large programs

Further Work

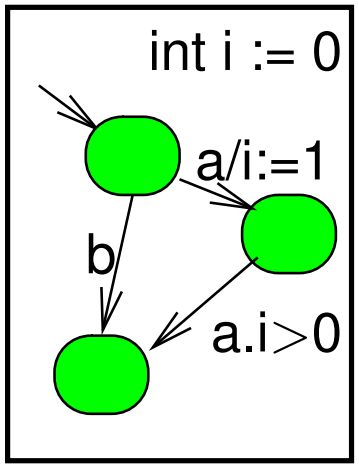
- Extension with variables
  - possible to respect encapsulation
- Extension to other synchronous languages
- Non-functional concerns in reactive contexts
  - Modeling of systems-on-a-chip
  - Modeling of sensor networks



Outline

Extension with Variables

- Difficulty: respect encapsulation
- Internal integer variables:
  part of implementation



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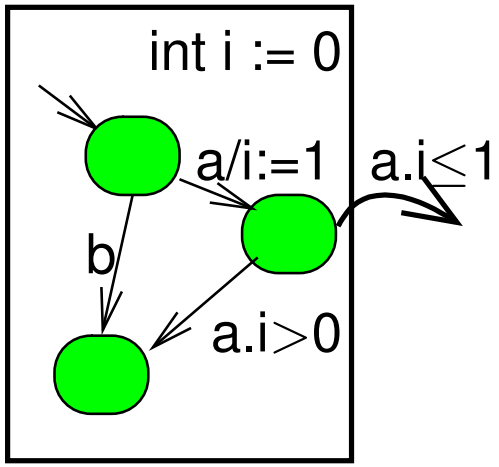

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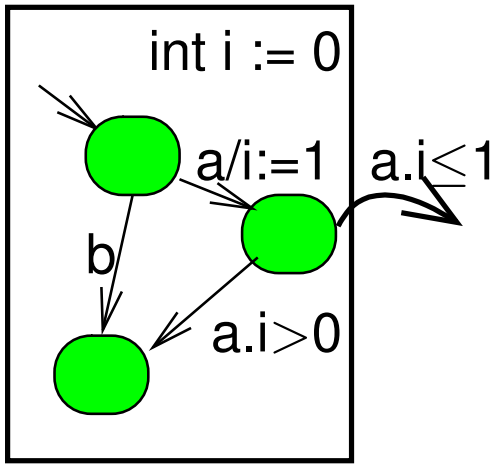

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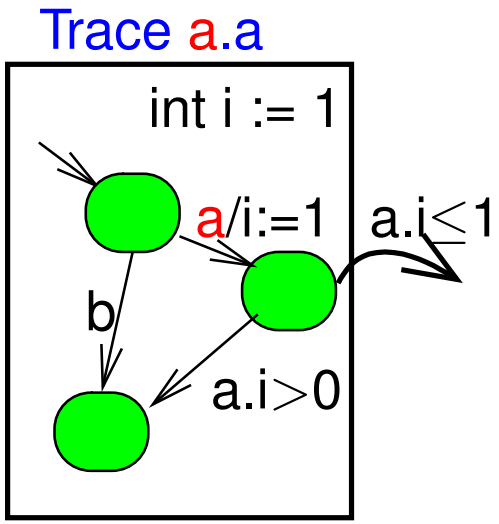

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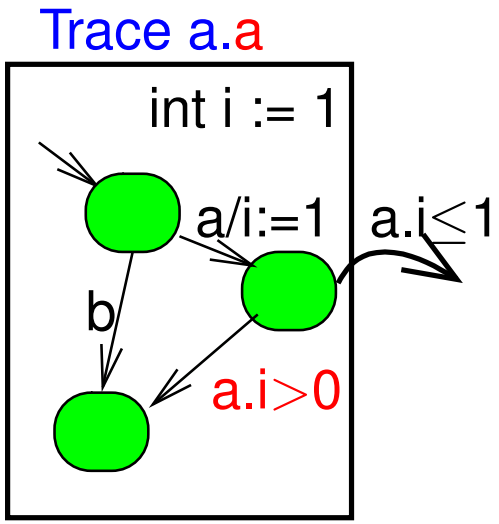

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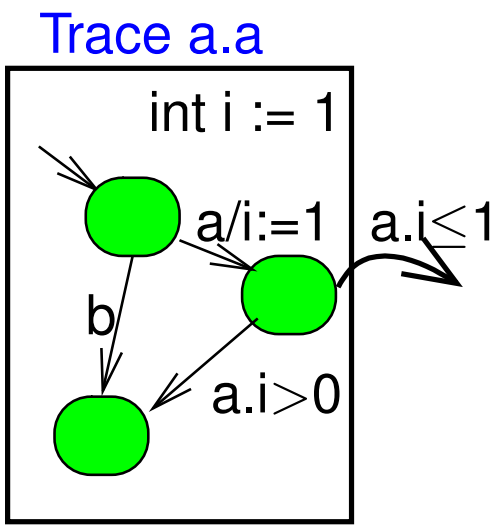
- Integer In/Outputs:
  - Aspect can modify outputs only if program cannot read them
  - i.e., o:=o+1 impossible



Aspect Languages for Other Synchronous Languages

- Synchronous languages have different styles:
  - Argos, Esterel: Imperative base + parallel composition
  - Lustre: purely parallel
- Adapt Larissa to other languages?
  - Pointcut: powerful, semantic, built-in everywhere
  - Advice: similar for Esterel (but trace automata specific)
  - Lustre: something different needed

Non-Functional Properties in Reactive Contexts

- Modeling and simulation of reactive systems
- Start by abstract functional model, add non-functional properties
- Non-functional properties often cross-cutting
- Identified two areas
  - Systems-on-a-chip: add timing information
  - Investigated in Quentin Meuniers Master's Thesis
  - Wireless sensor networks: energy consumption

Contract Weaving — Technical Overview

- Problem: aspects cannot be applied directly to observer automata

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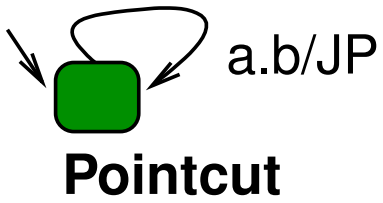
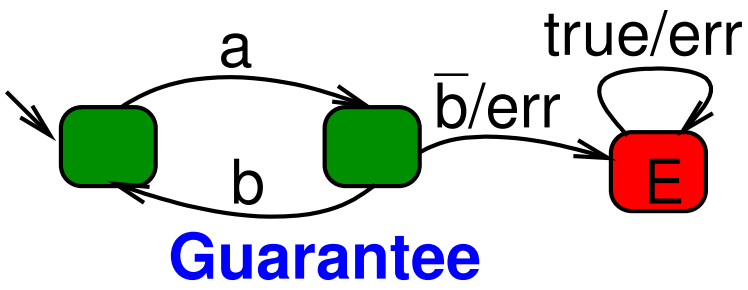
- Problem: aspects cannot be applied directly to observer automata
- Solution:
  - Transform observers into generator automata *nd*
  - Apply aspect to generators
  - Transform woven generators back to observers *obs*
  - Different for assumption and guarantee:
    - $A' = obs_A(nd_A(A) \triangleleft asp)$
    - $G' = obs_G(nd_G(G) \triangleleft asp)$
- Then,

$$P \models (A, G) \Rightarrow P \triangleleft asp \models (A', G')$$

Example – Guarantee Weaving

- Example aspect: advice output b, trace a





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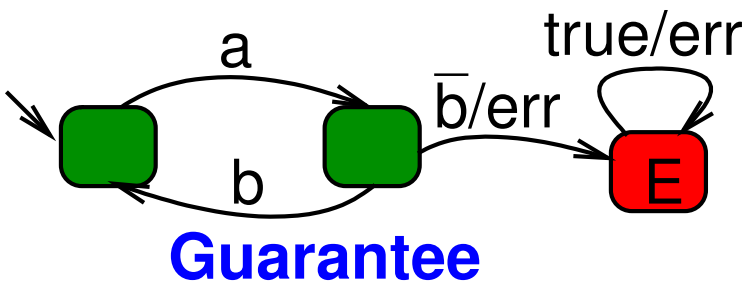

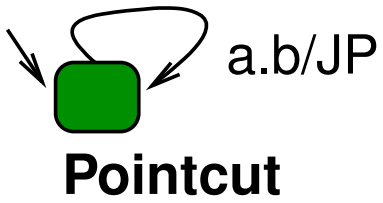

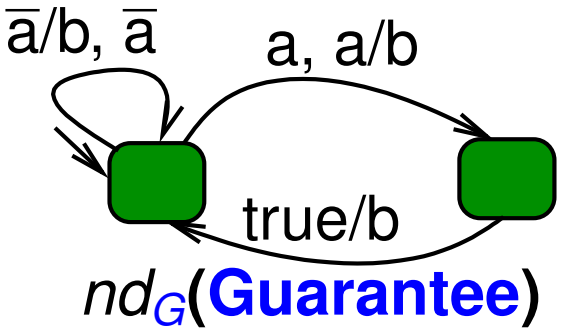

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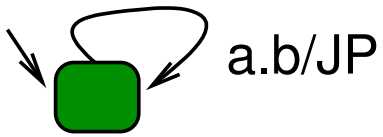
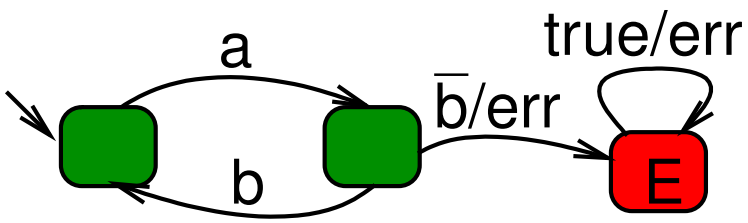
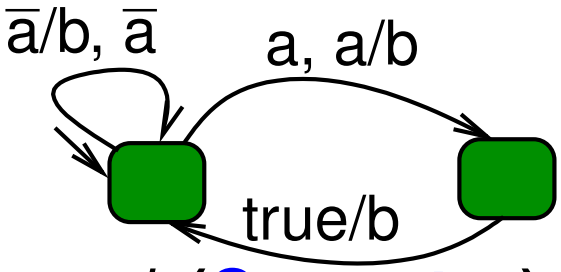


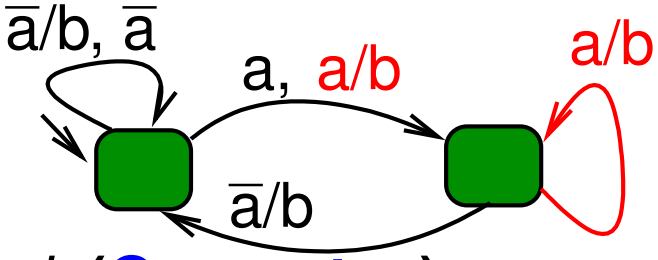
Pointcut



Guarantee



nd_G(**Guarantee**)



nd_G(**Guarantee**)$\triangleleft$*asp*

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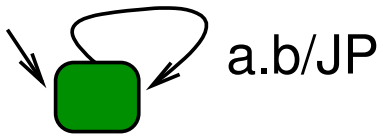

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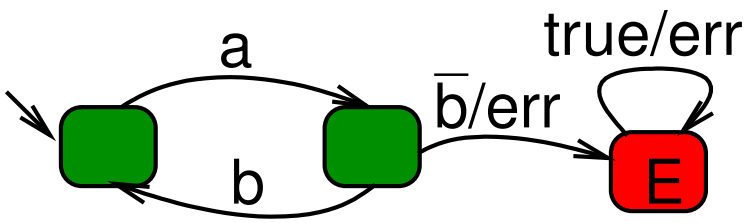

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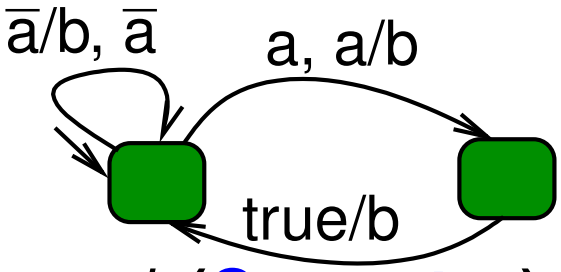

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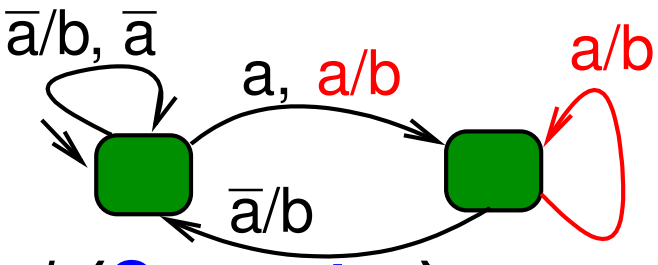

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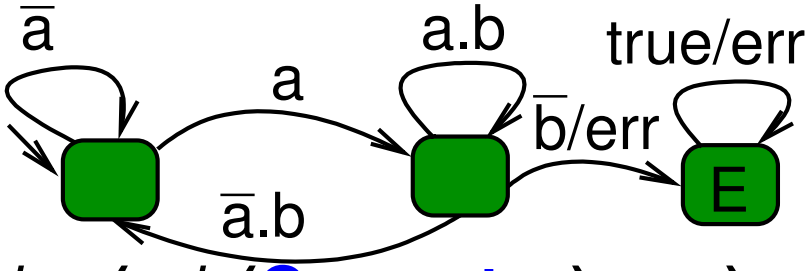
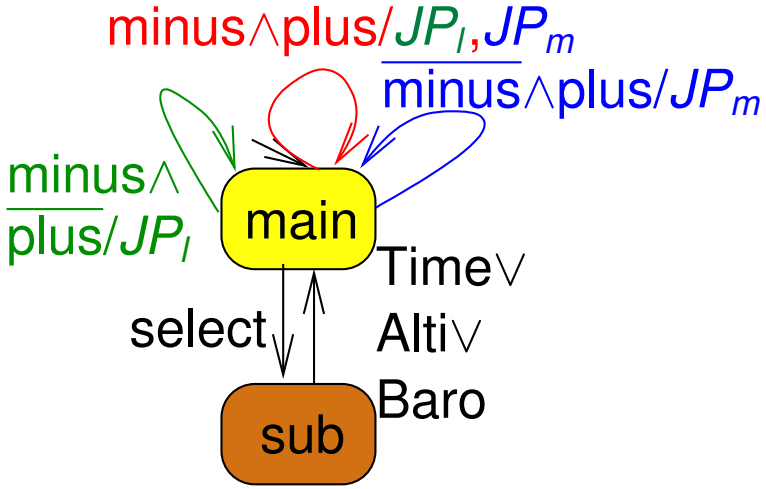


obs_G(nd_G(**Guarantee**)$\triangleleft$*asp*)

Interference: Shortcut Aspects

- Use first method: calculate product of two pointcuts



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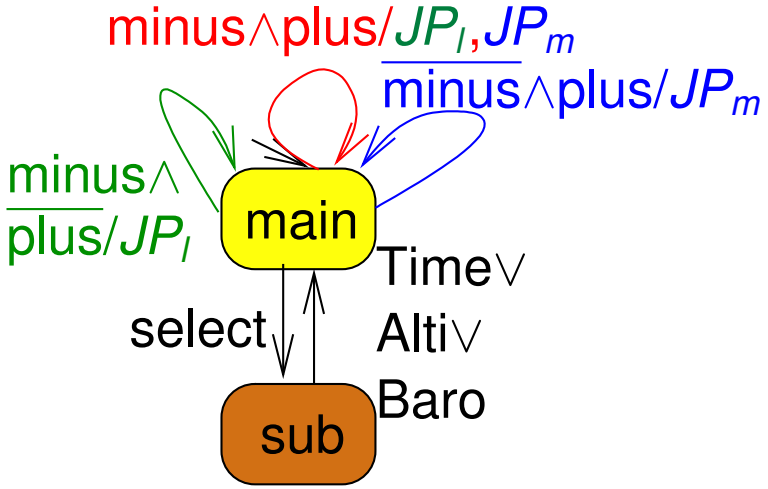


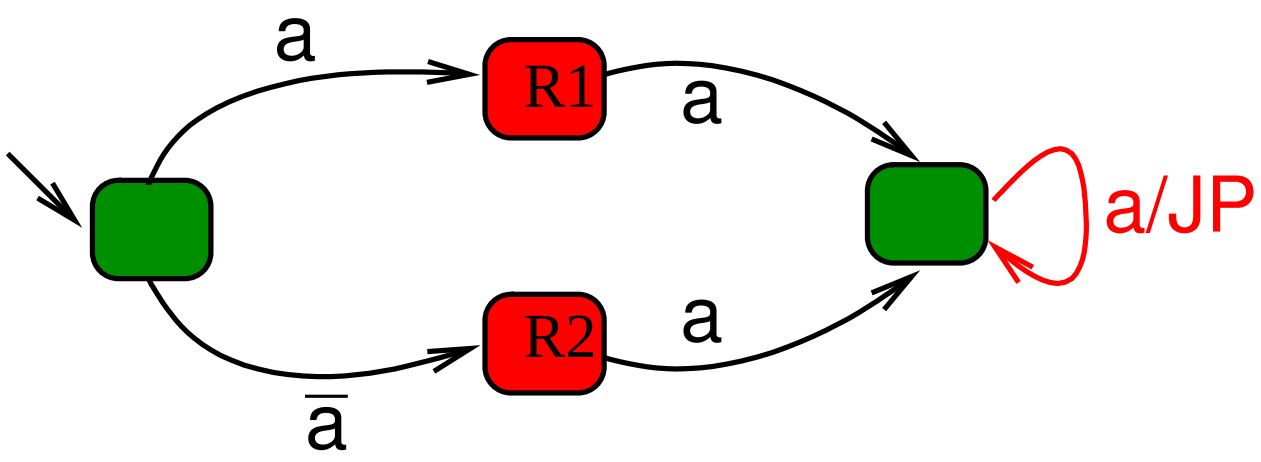
- Aspects interfere when both buttons are pressed at the same time in a main mode
- Product tells us exactly where aspects may interfere

Recovery Advice

- toInit advice: jumping to a fixed location
- toCurrent advice: jumping forward
- Missing: jumping backwards
- Specification with trace impossible: automaton not deterministic
- Different solution:
  - specify recovery states in base program
  - target state of advice transition: the last recovery state passed

Example

- Example: R1, R2 recovery states (selected by an observer)
- Return to recovery state that was passed last



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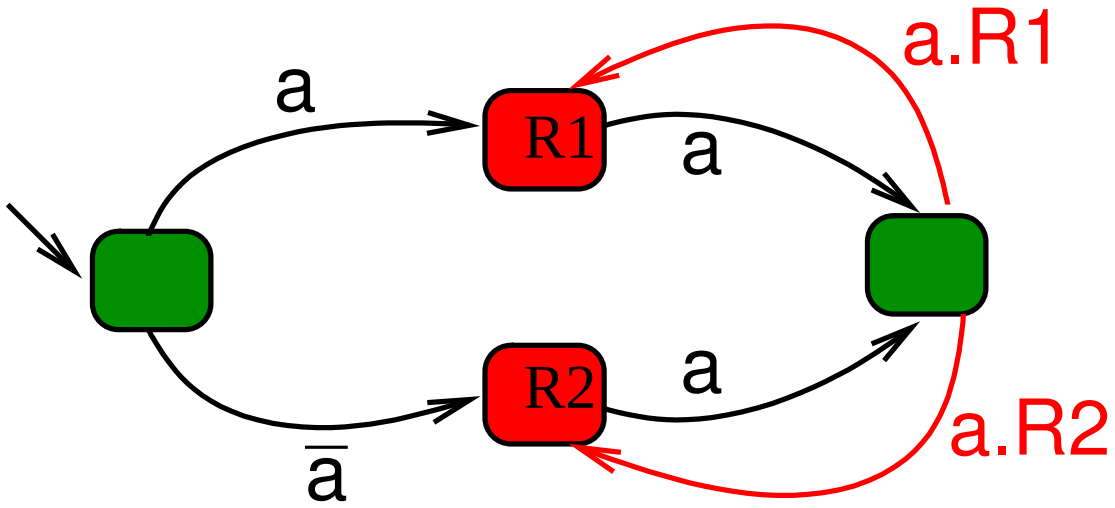

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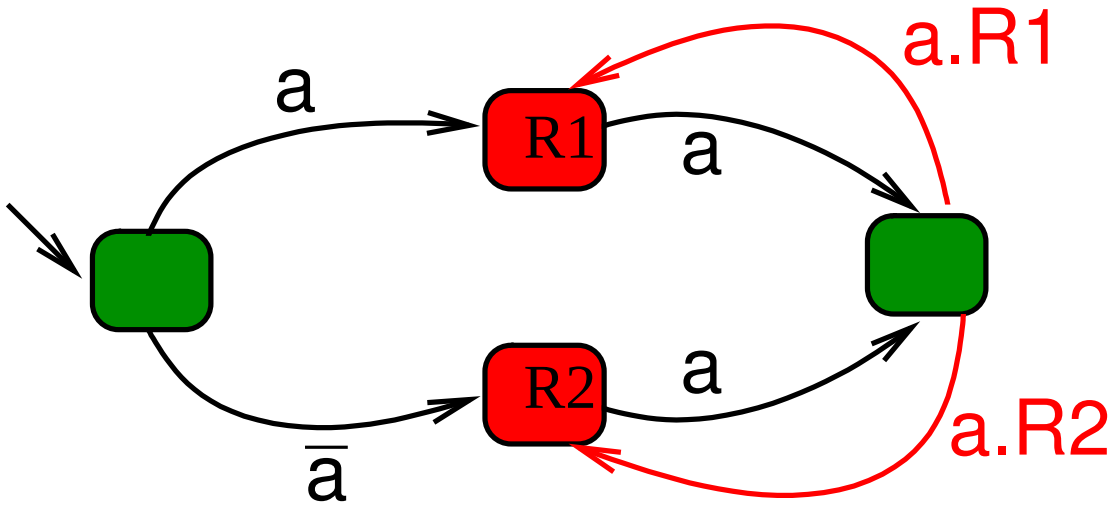

- Signals R1 and R2 decide which transition is taken
- Must be emitted by an Memory Automaton, run in parallel, which remembers which recovery state was passed last