High-level Supervision of Program Execution Based on Formal Specification

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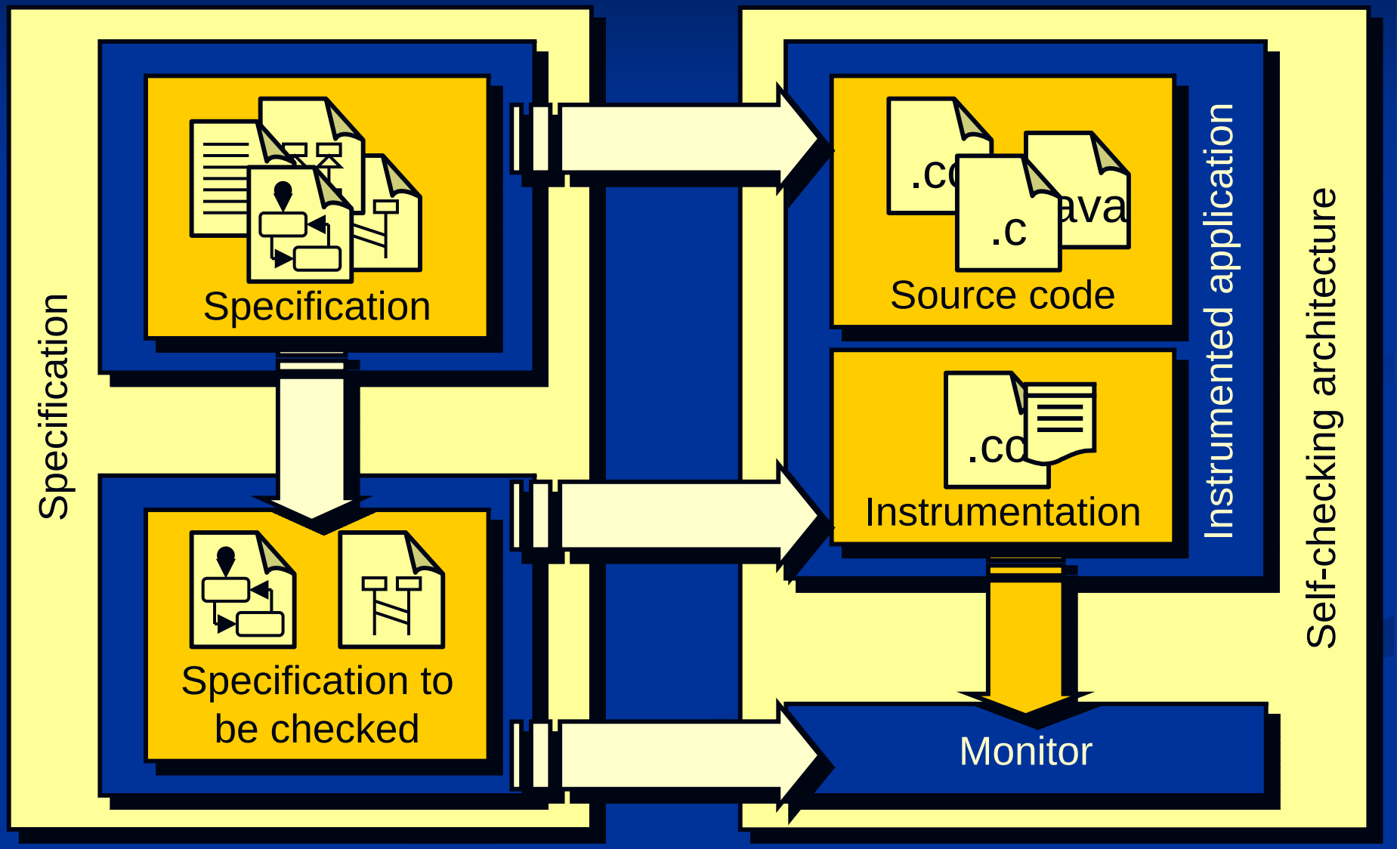
Research goals

- Run-time fault-detection architecture based on the abstract specification
  - Behavioral models (e.g. statecharts)
  - Communication protocols (e.g. live sequence charts, sequence diagrams)
- Configurable granularity of observation
  - Selection of key aspects of the specification (e.g. by Temporal Logic Formulae)
- Supporting safety-critical SW architectures (e.g. EN-50128)

Run-time verification against formal models



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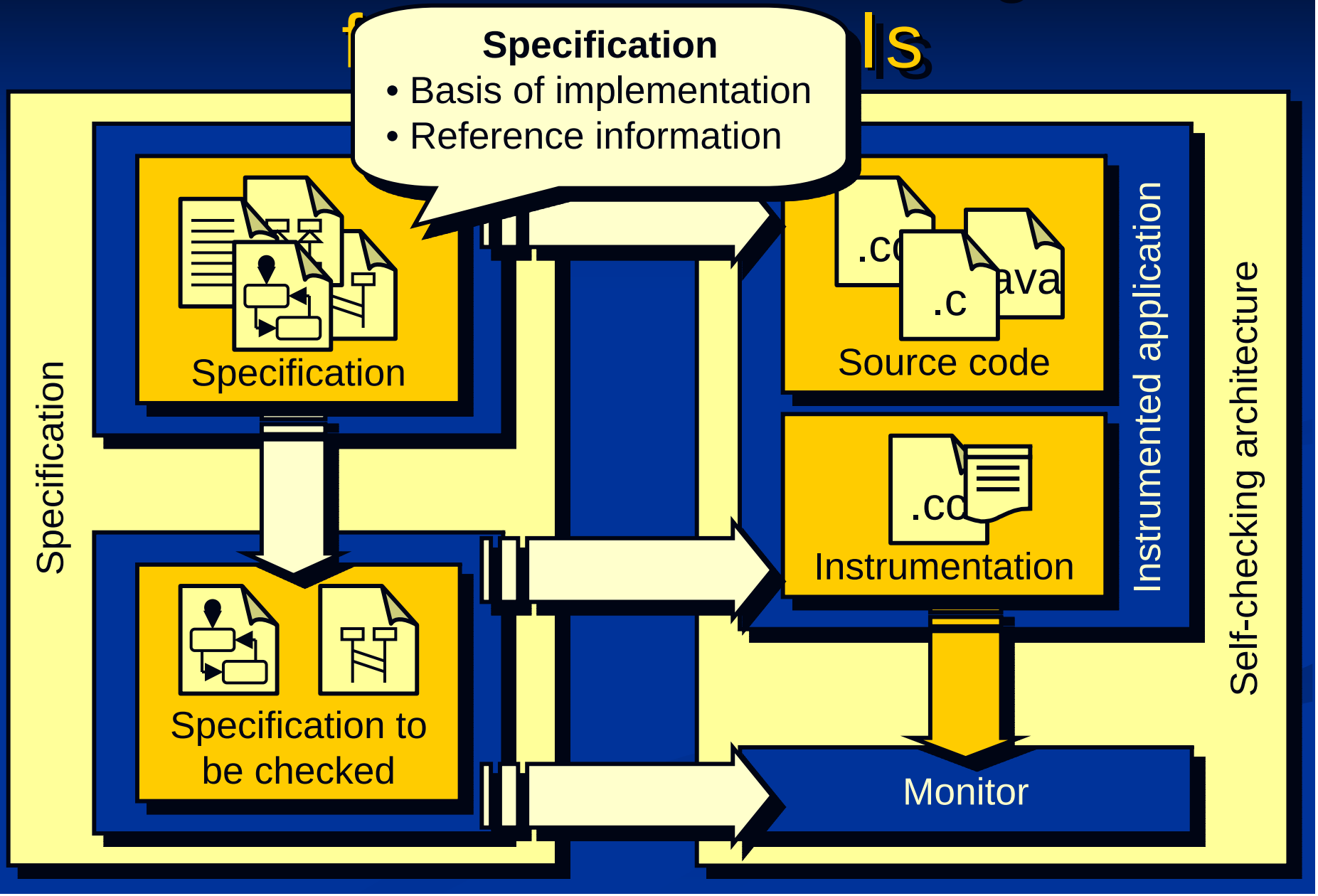

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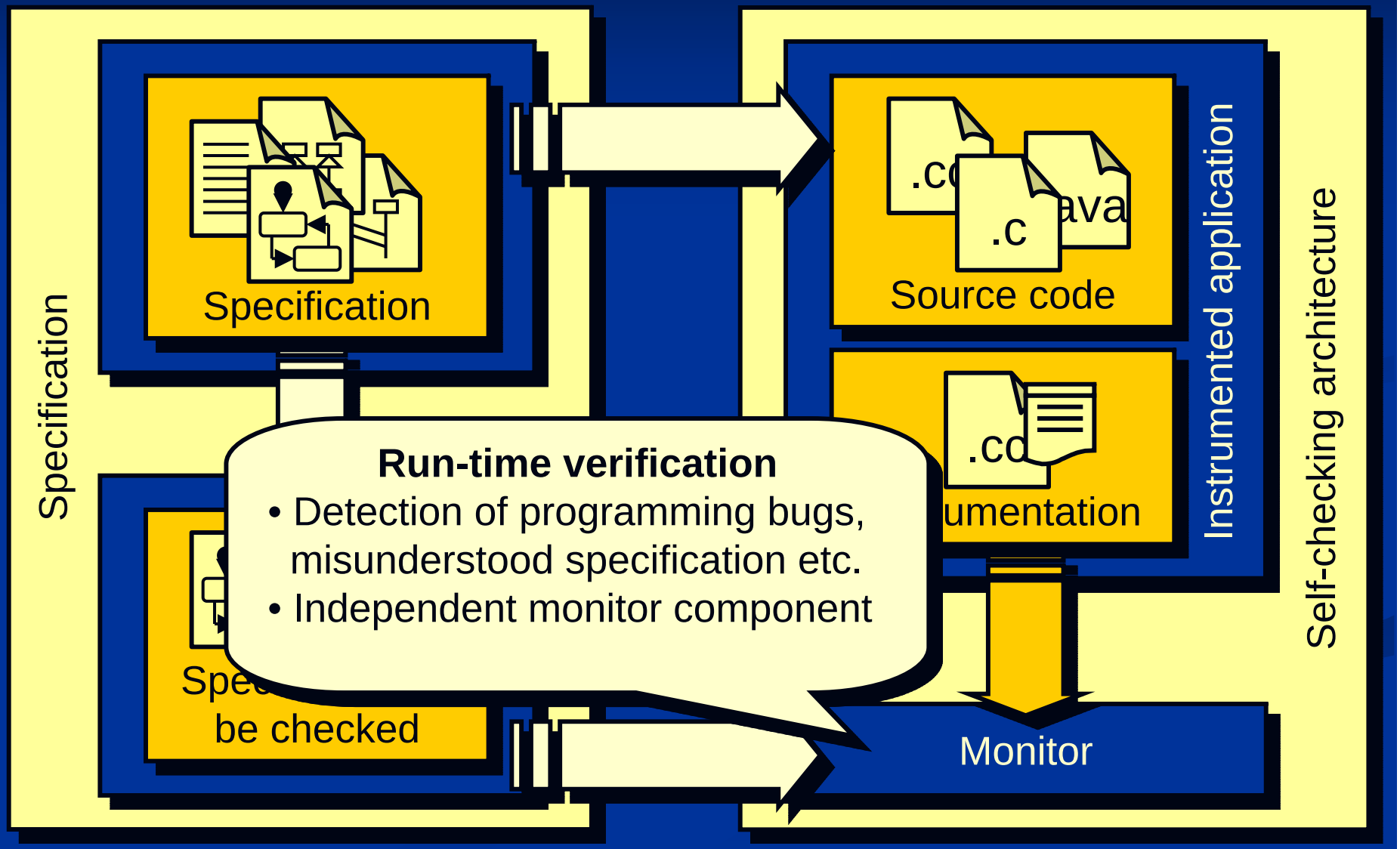

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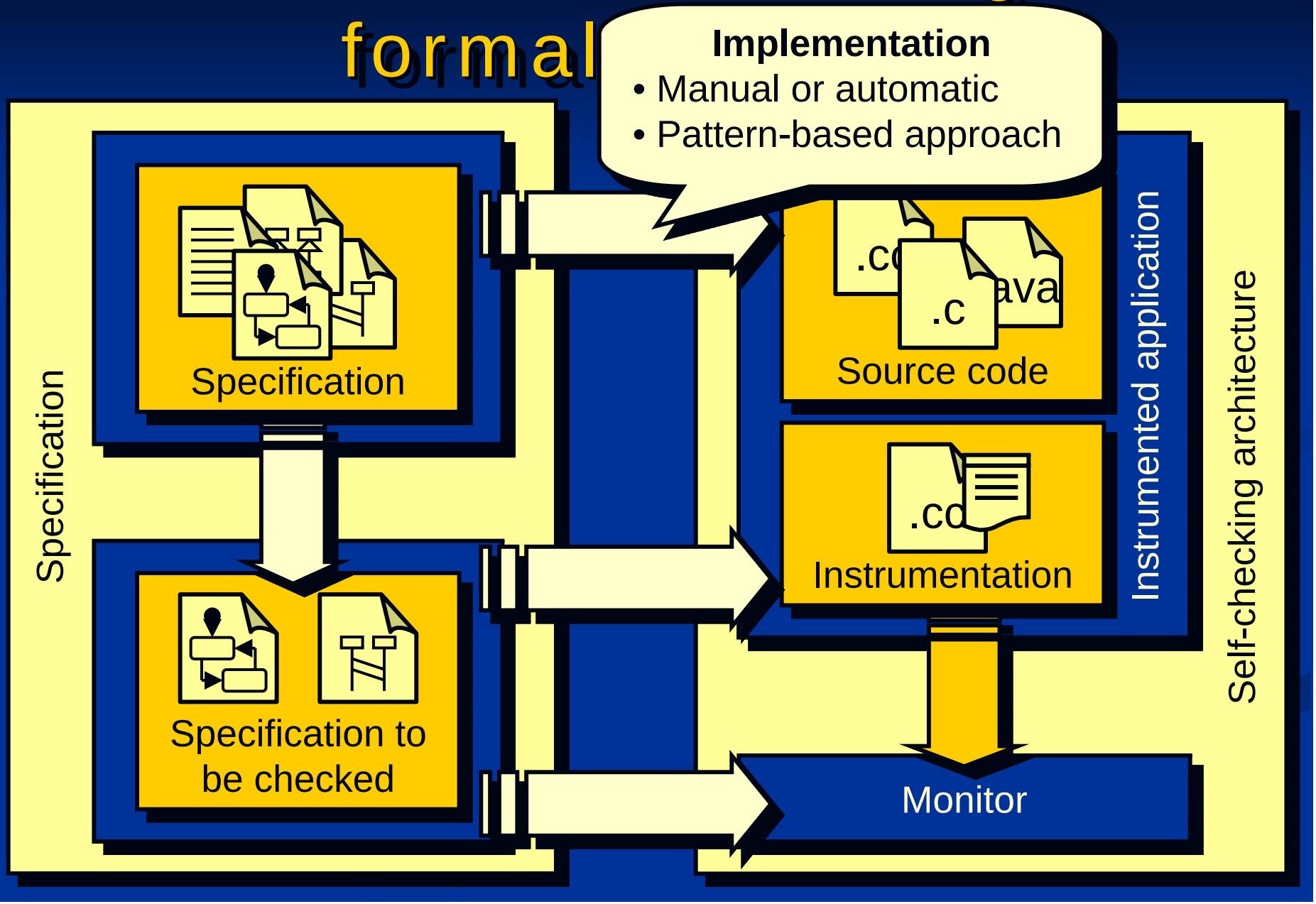

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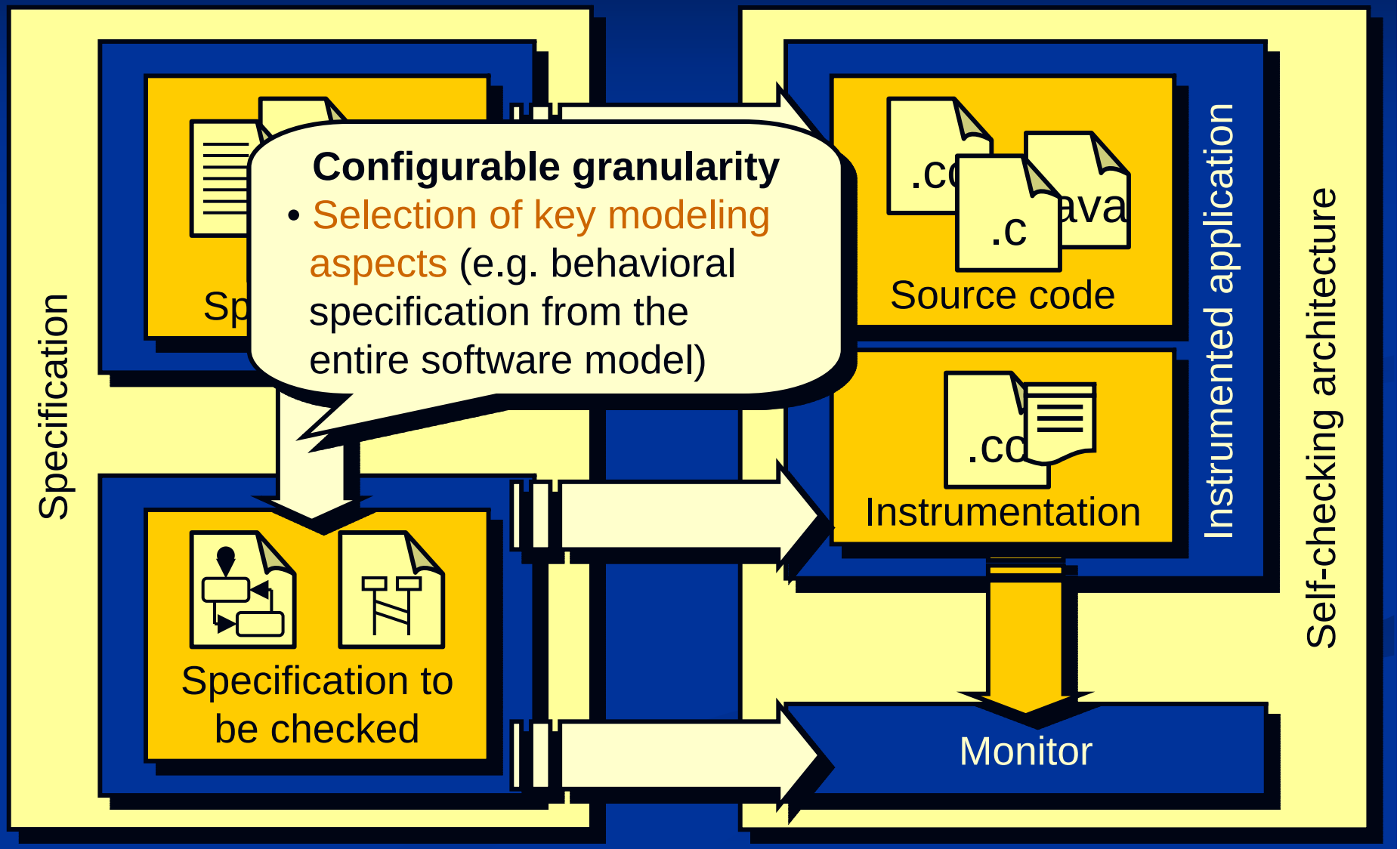

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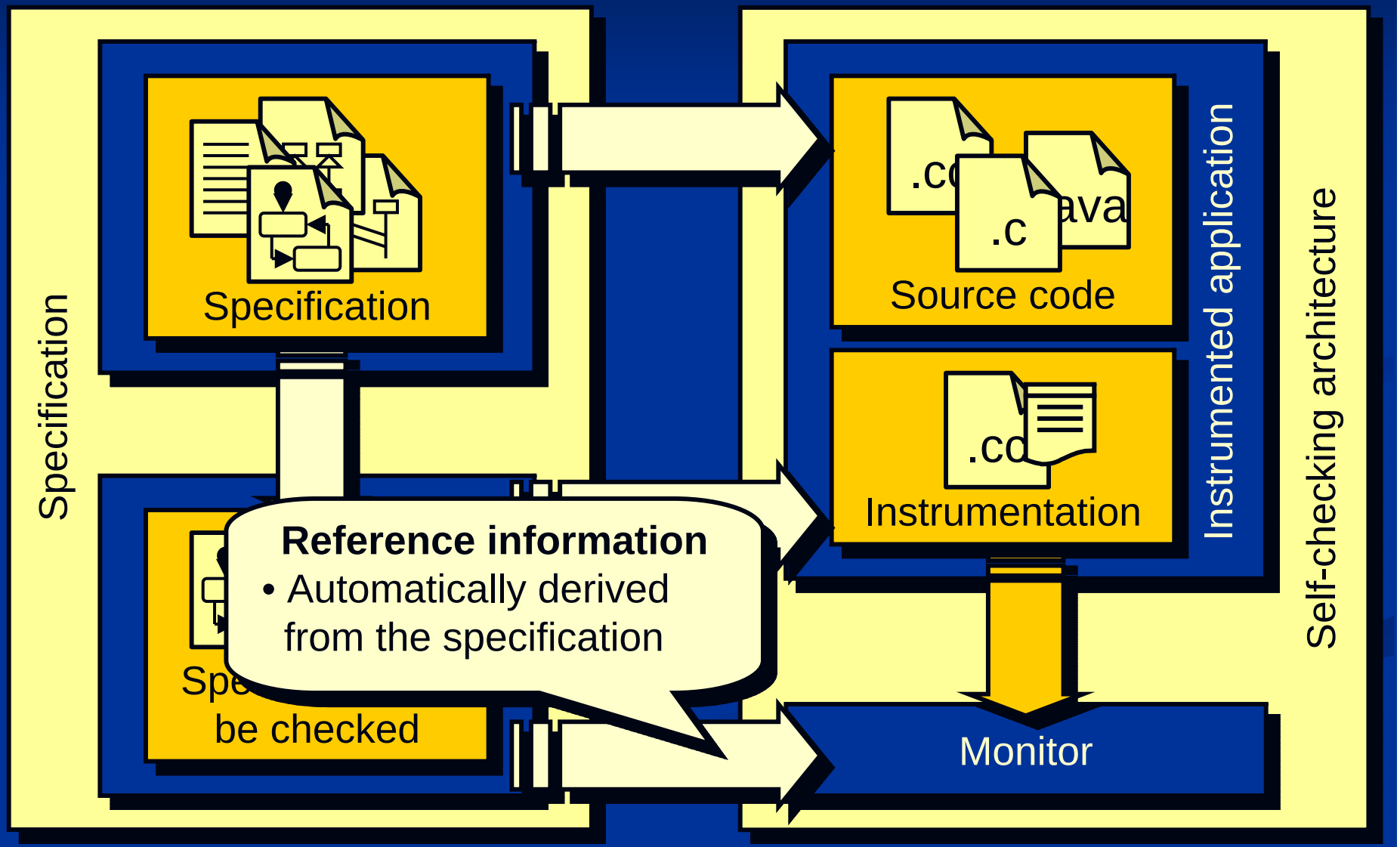

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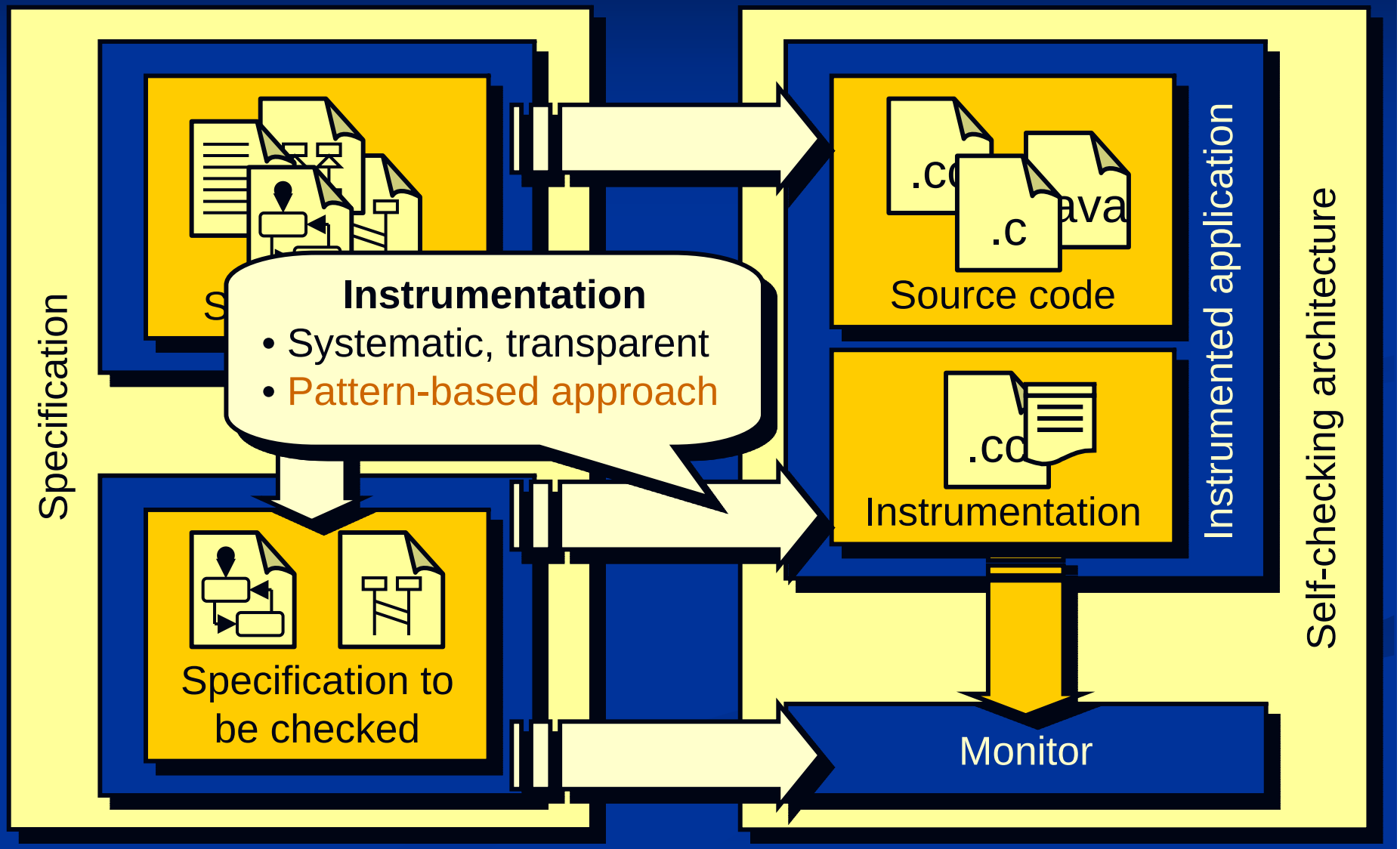

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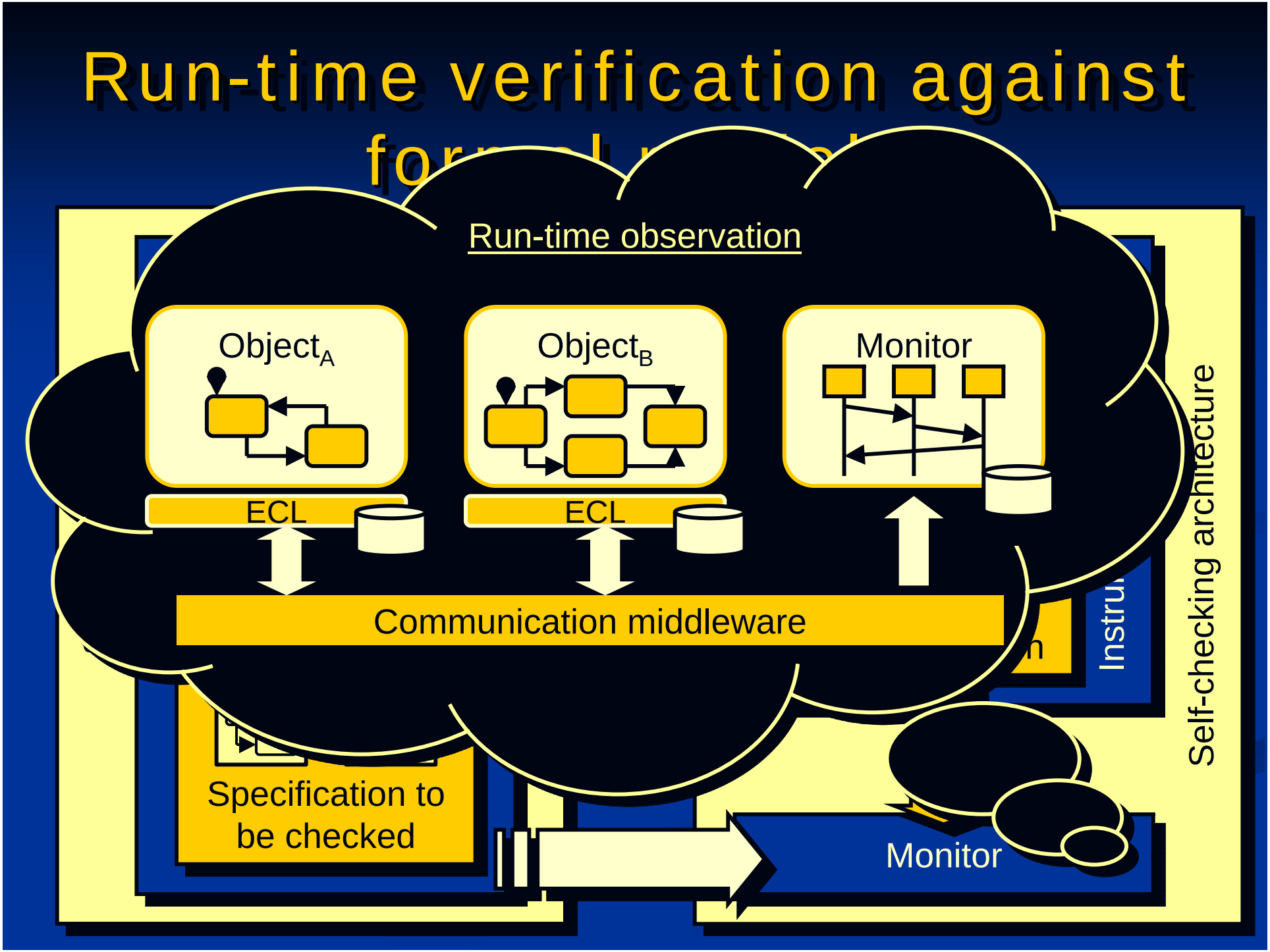

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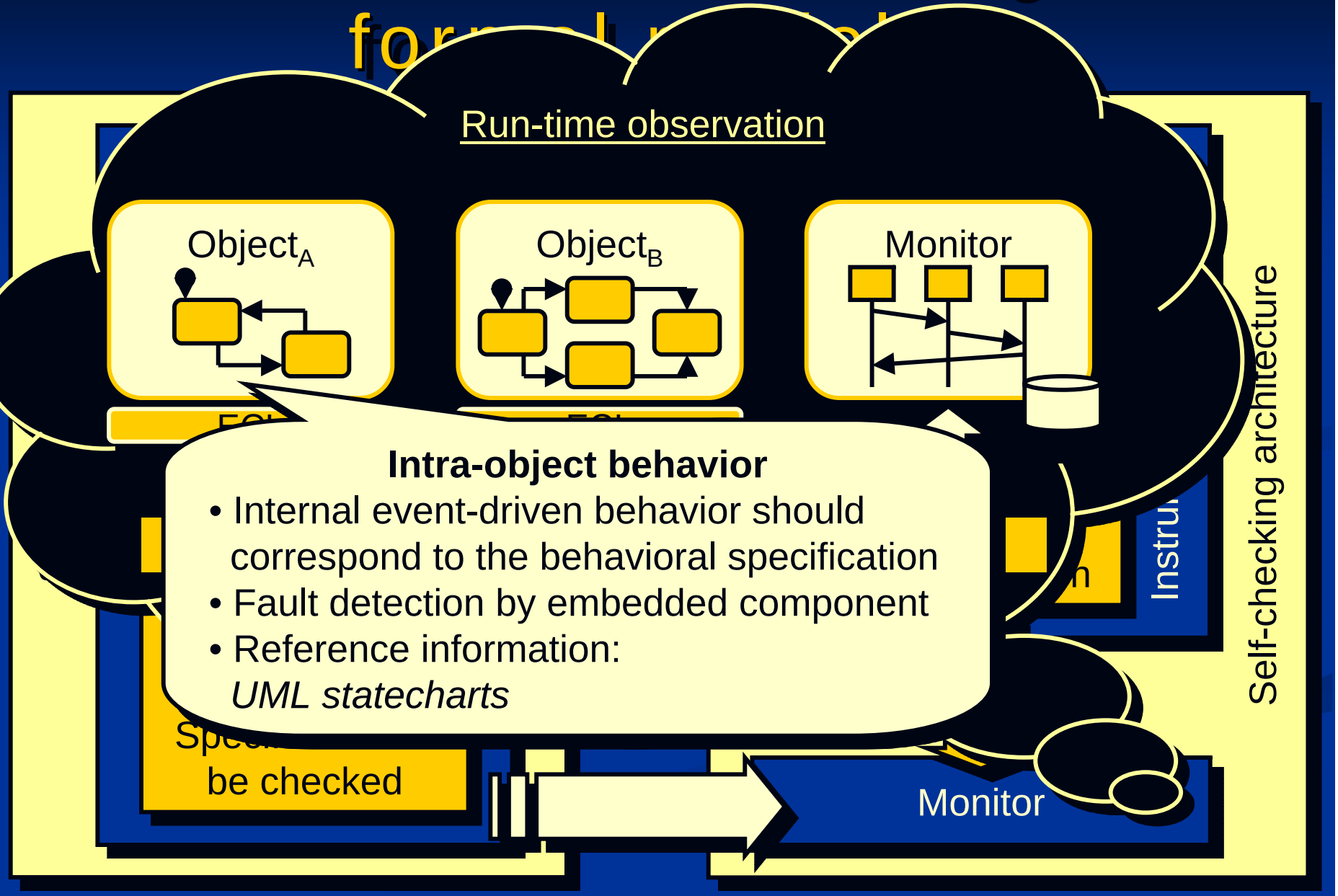

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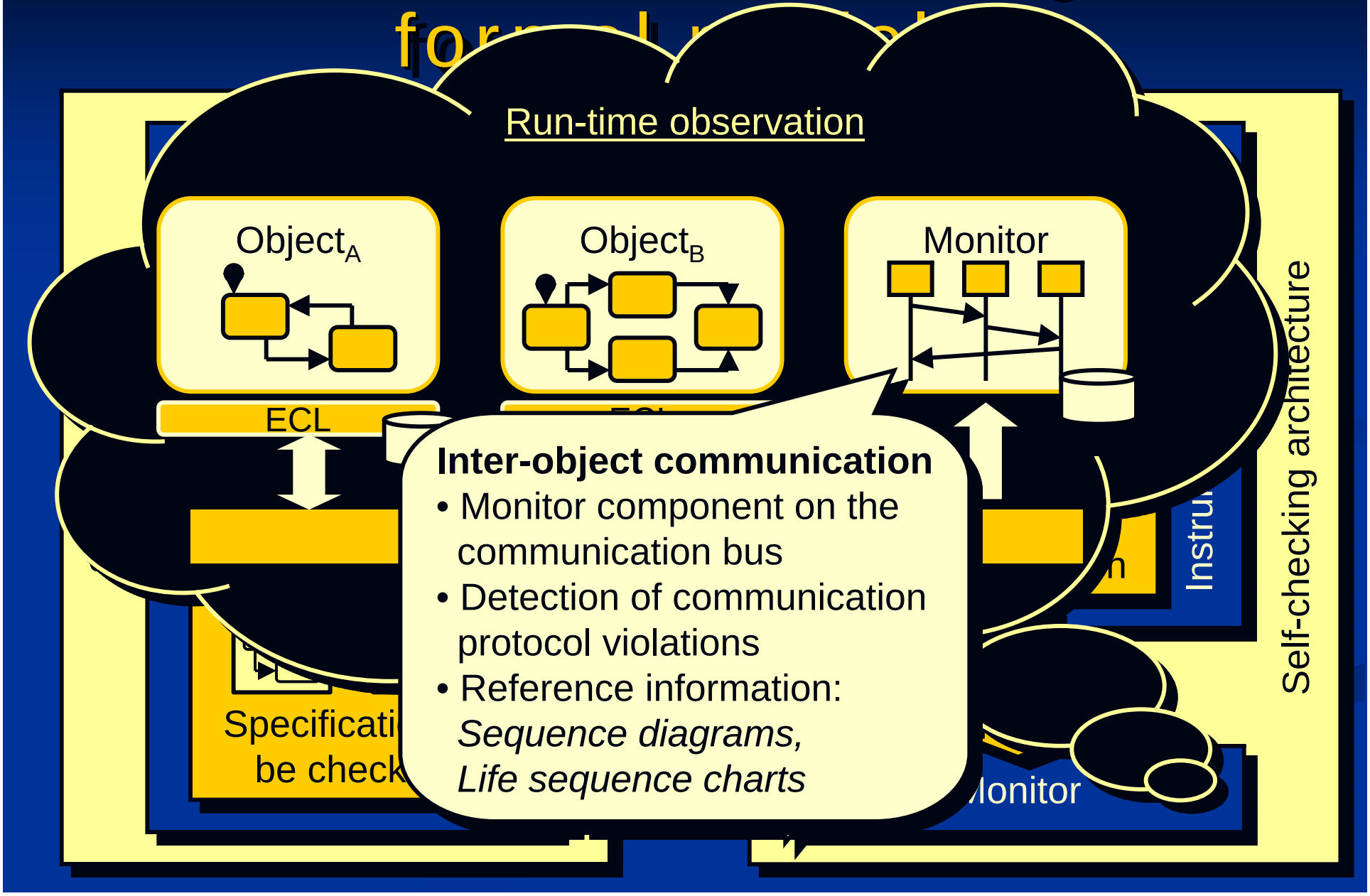

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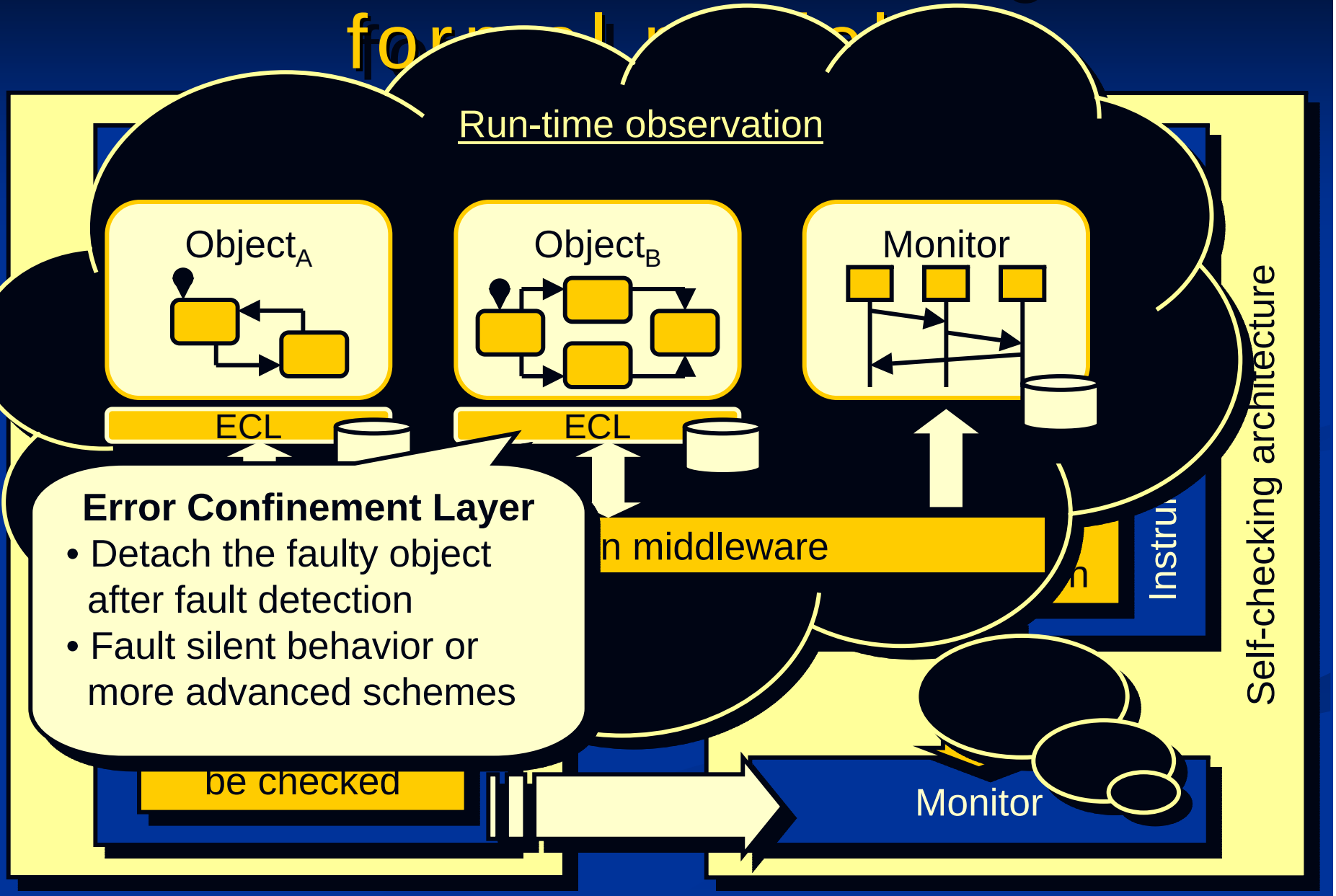

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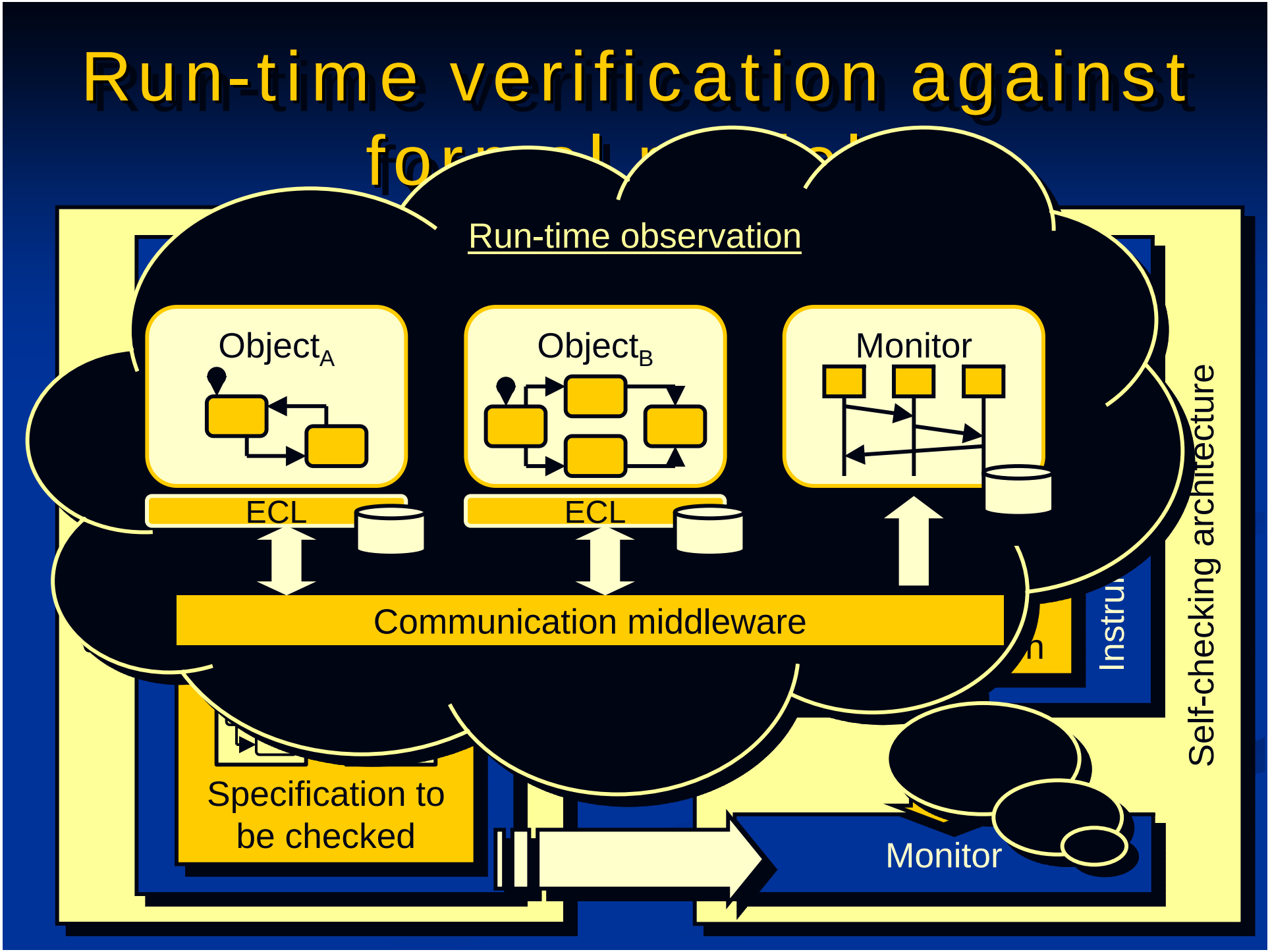

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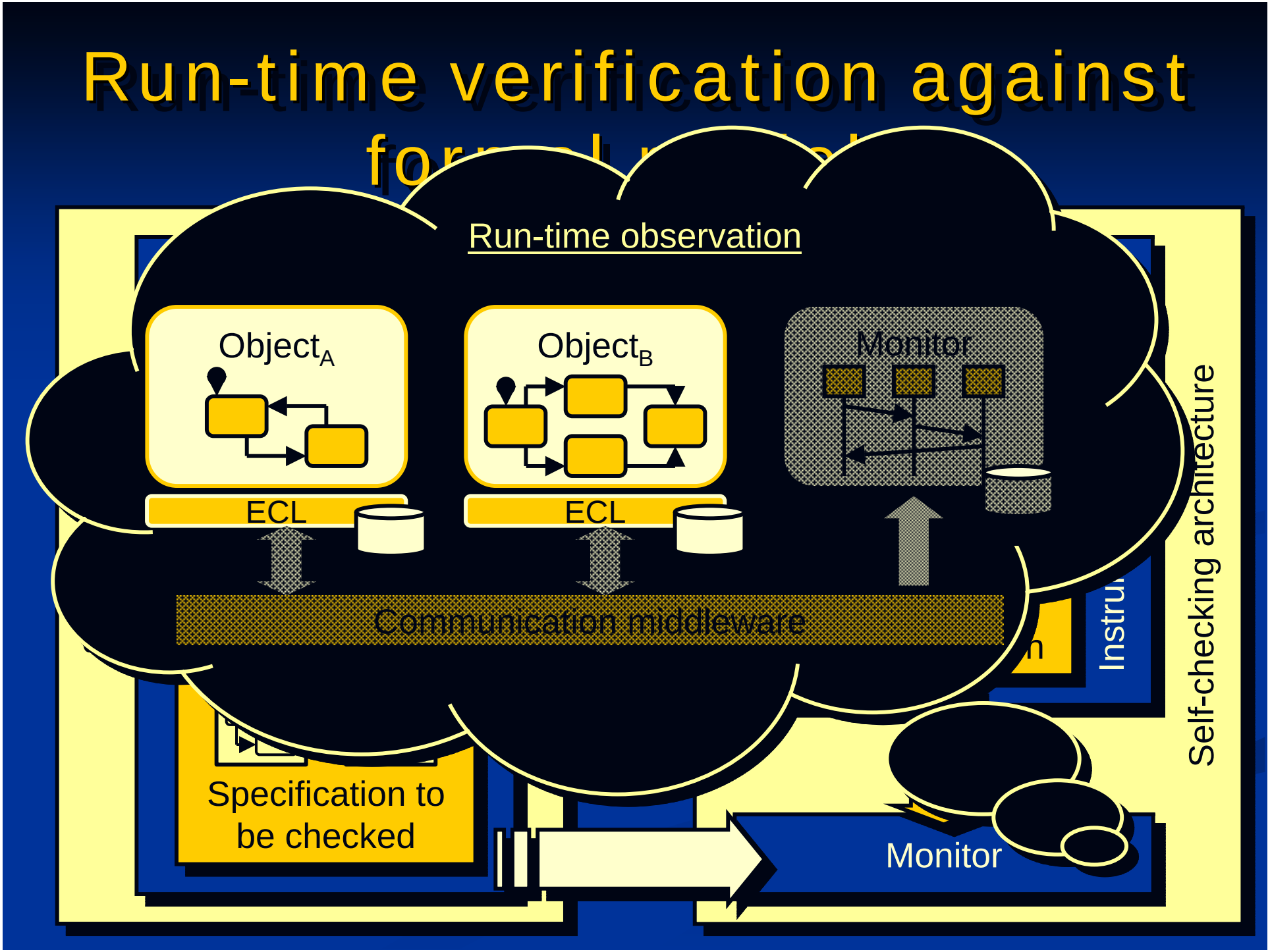

Run-time v
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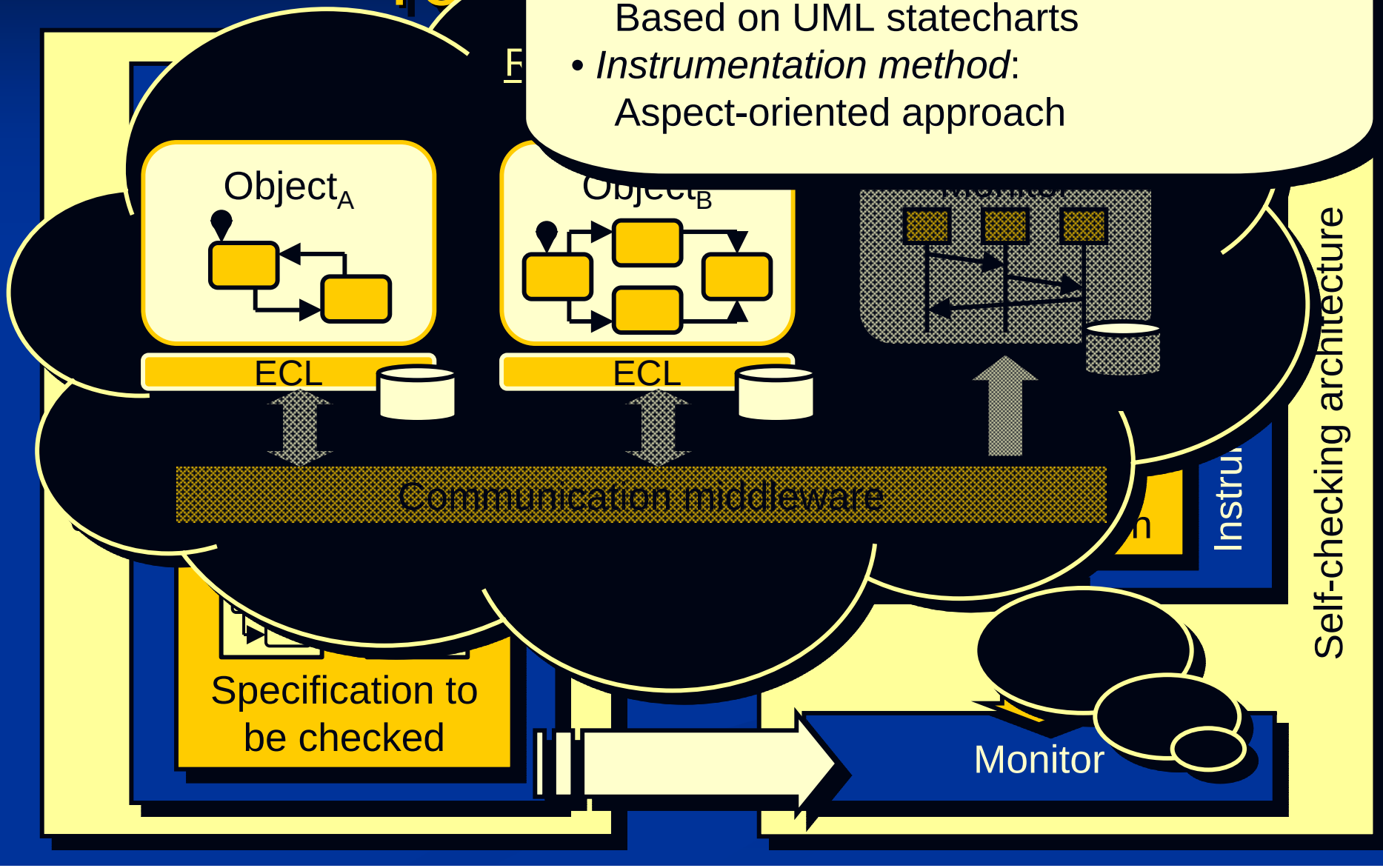
Focus and Contribution

- Run-time observation of *internal behavior*
- Advanced *monitoring mechanism*:
  Based on UML statecharts
- *Instrumentation method*:
  Aspect-oriented approach



Abstract, high-level control-flow fault detection

Reference information:
- Automatically derived from the behavioral specification
- Capable of expressing state hierarchies, concurrent operation, etc.

Implementation of the monitor:
- Based on the operational semantics of the behavioral model
- Run-time checking of the behavior on the basis of the abstract reference model

Implementation of the instrumentation:
- Providing information to the monitor about the internal behavior
- Configurable, transparent and automatically applied

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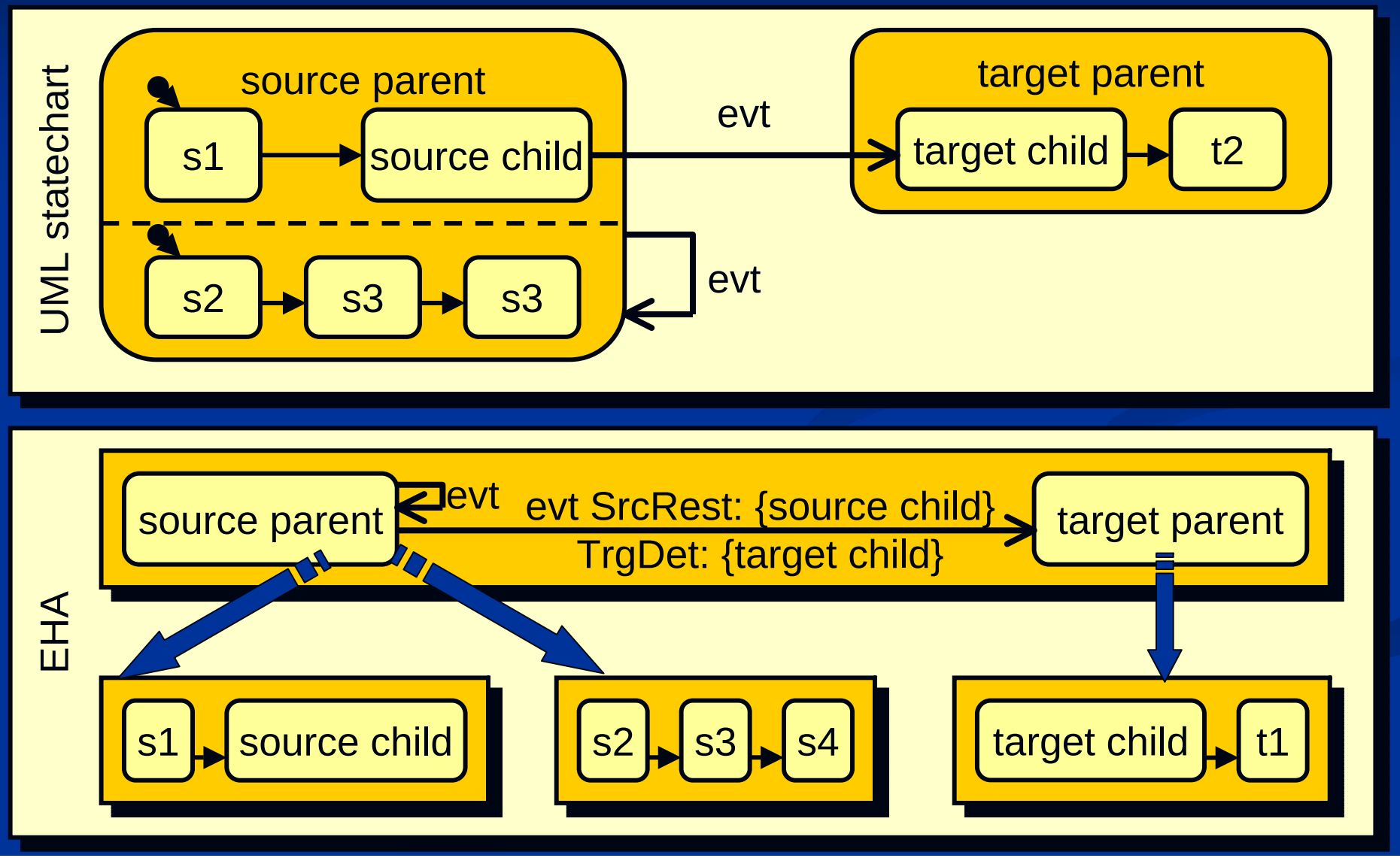
Reference information of the internal behavior

- Extended Hierarchical Automata (EHA)
  - Clear structure:
    - Sequential automata:
      Containing any number of states
    - Non-composite states:
      Refined to any number of sequential automata
    - Non-interlevel transitions:
      Source restriction and target determination sets
  - Well elaborated formal semantics
  - Automatically derived from UML statecharts

Reference information of the internal behavior



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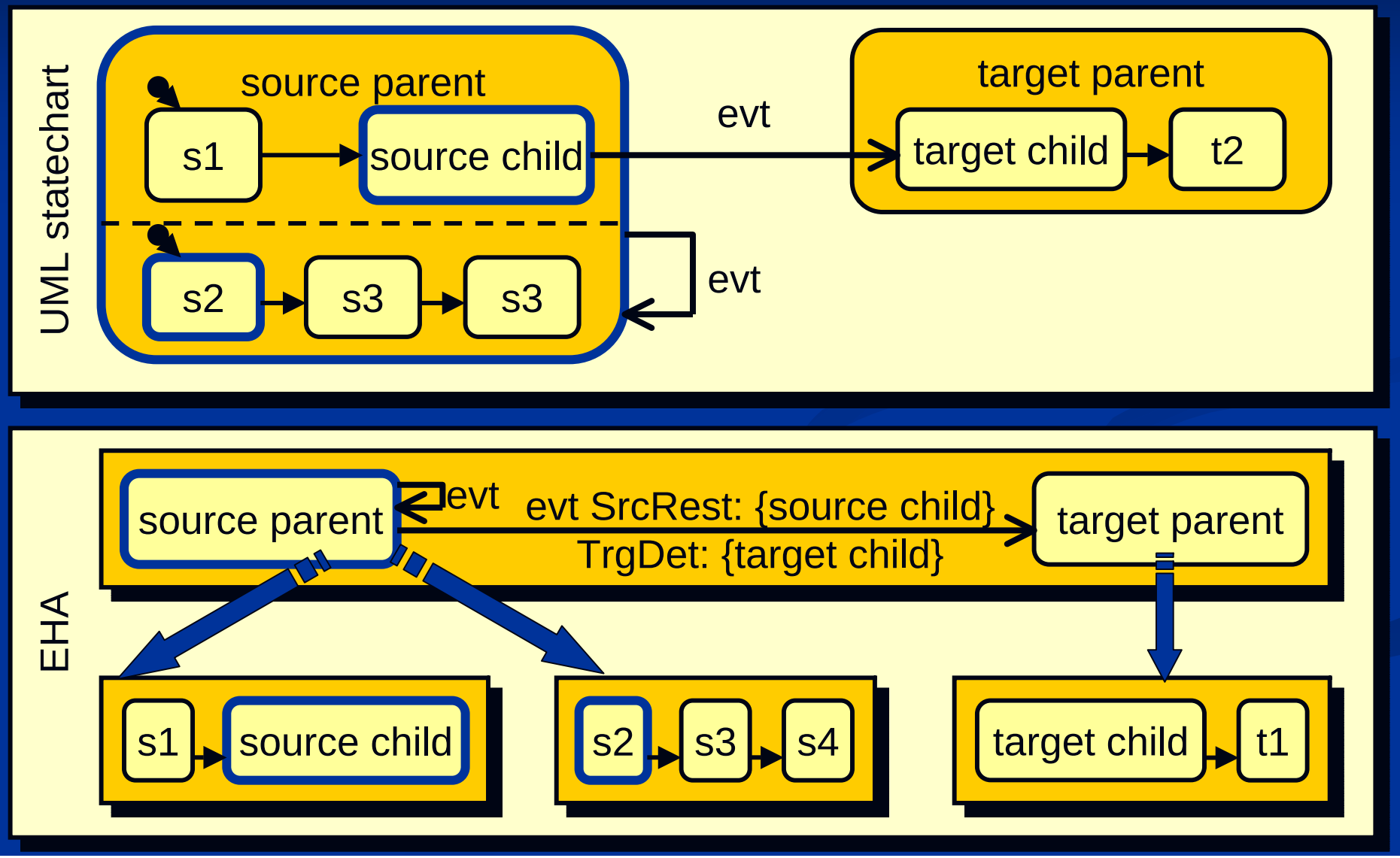

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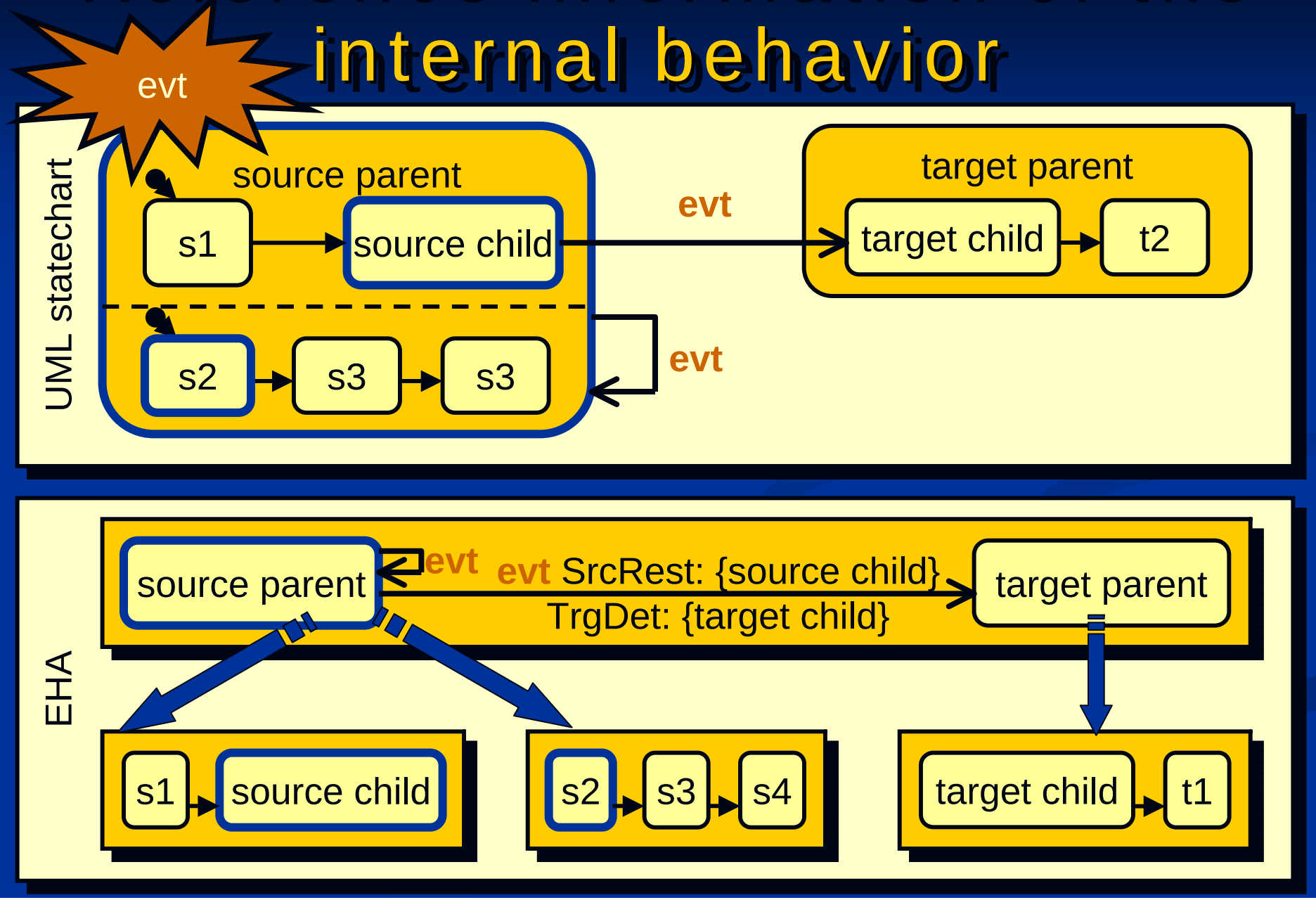

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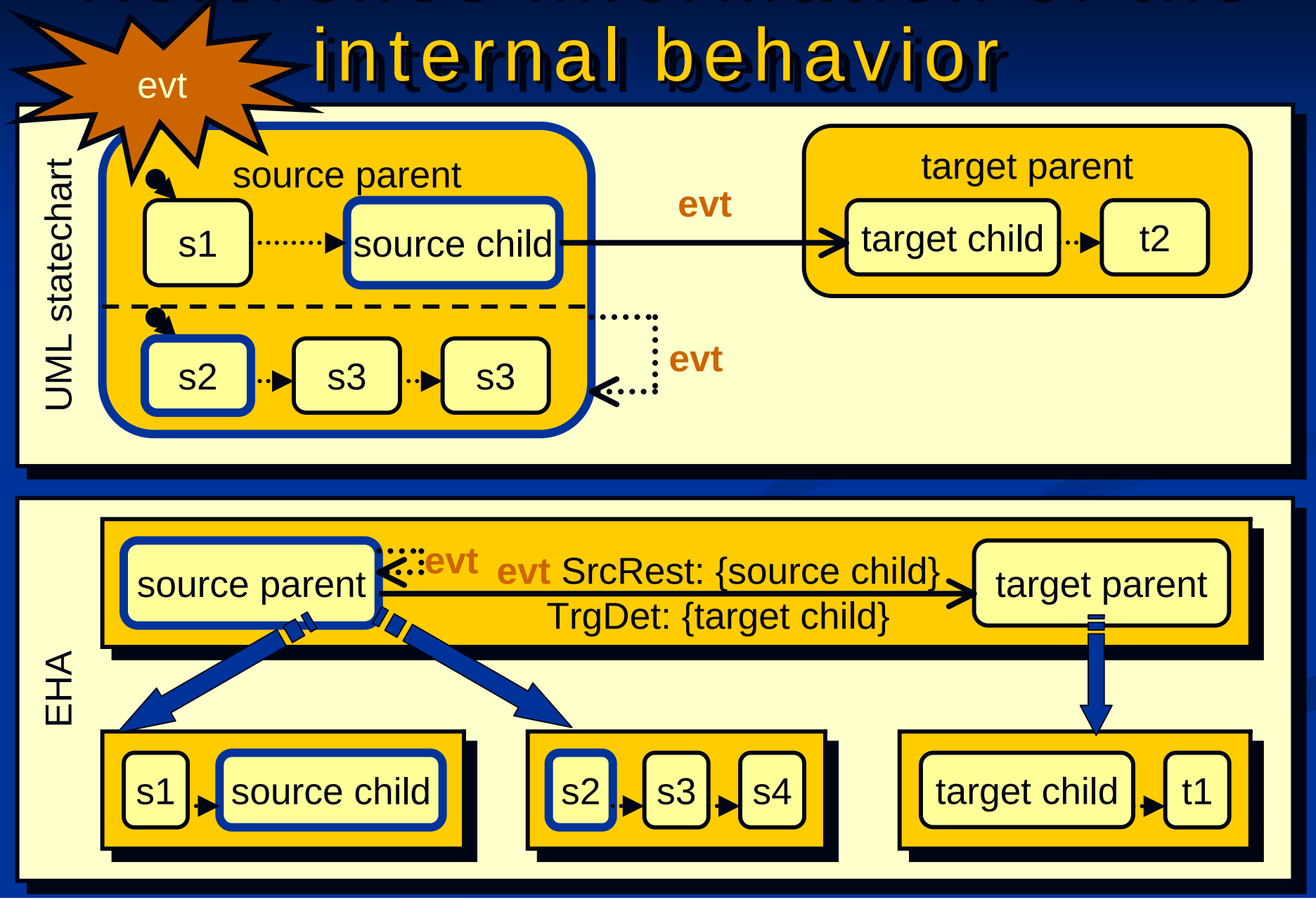

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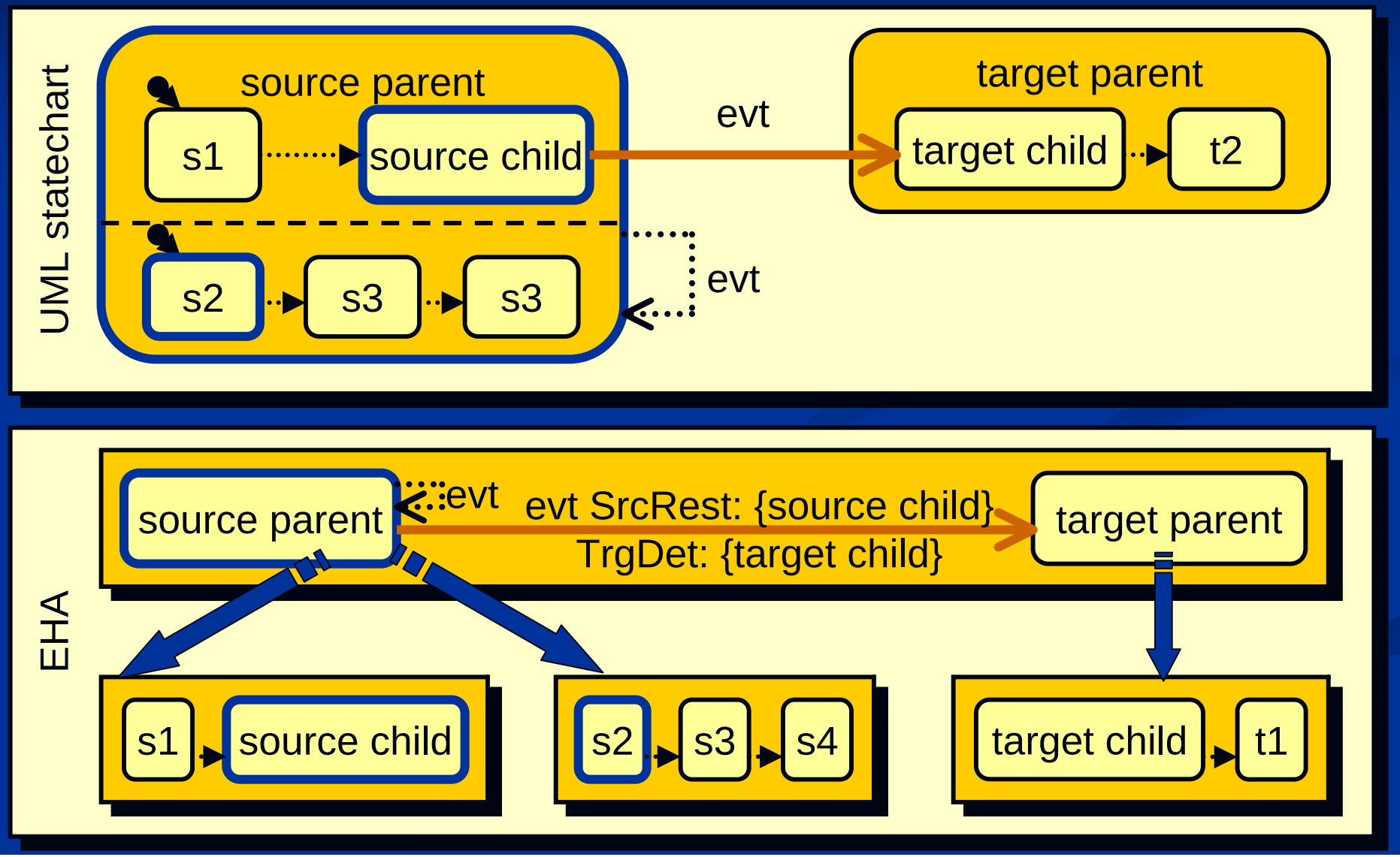

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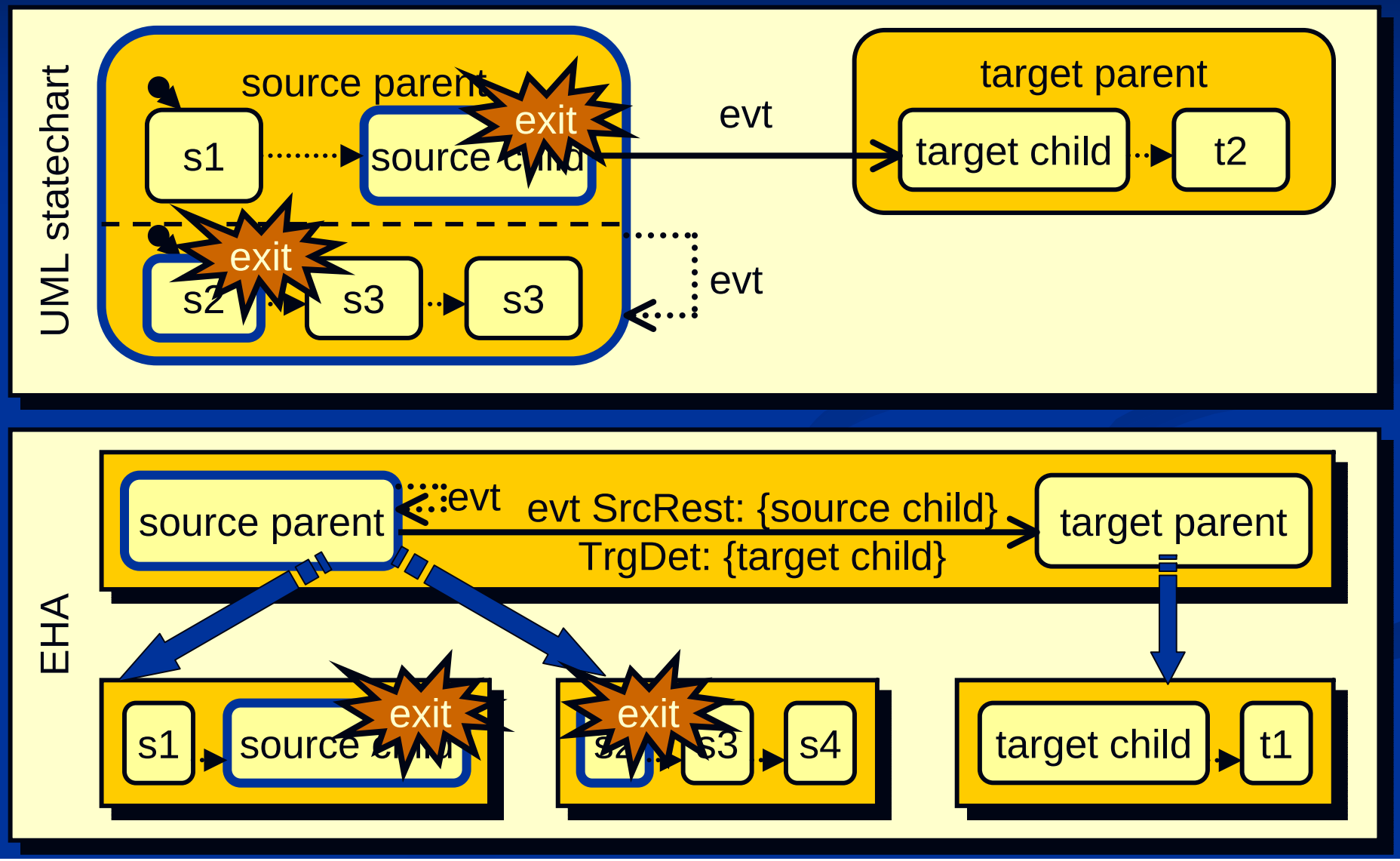

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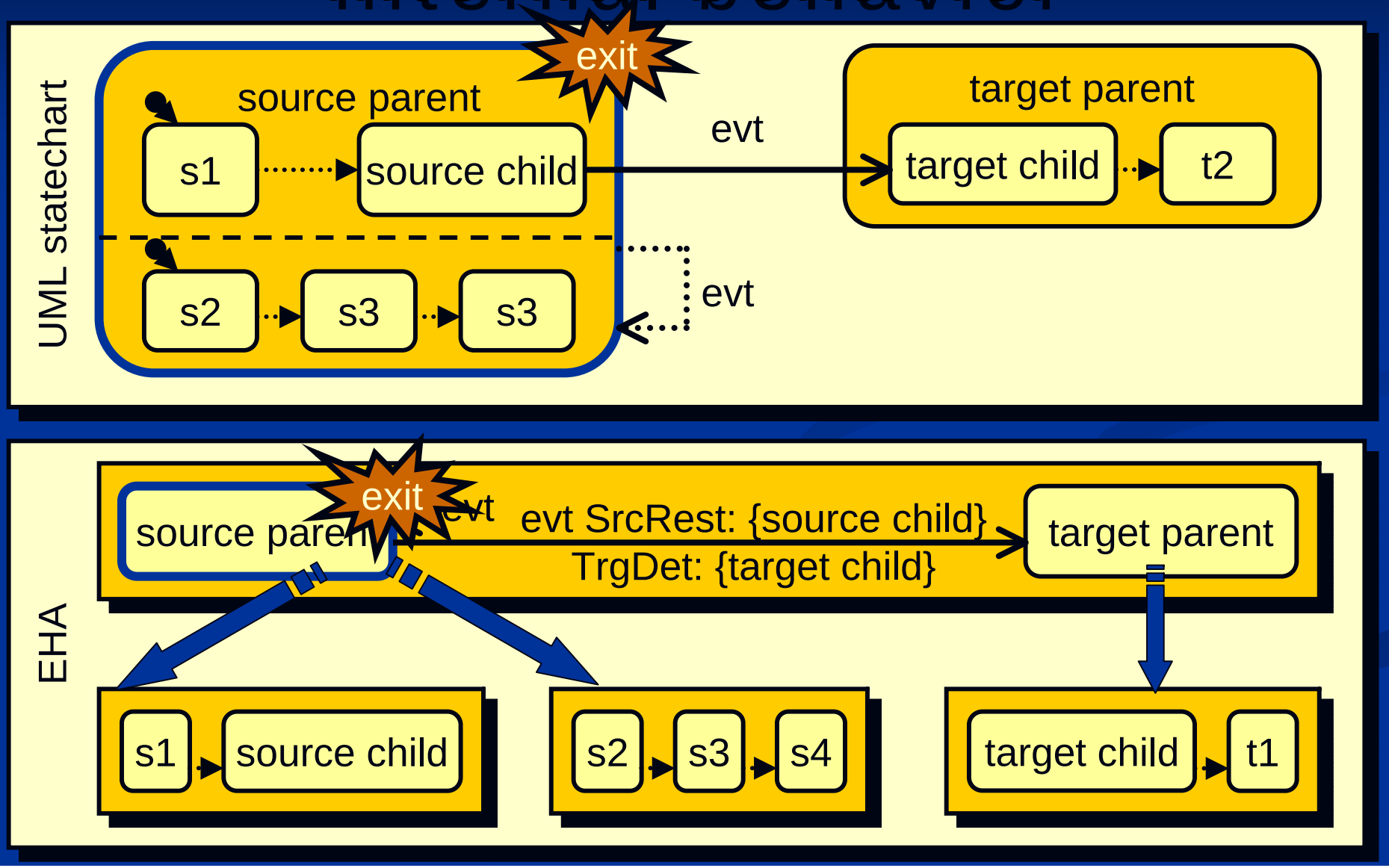

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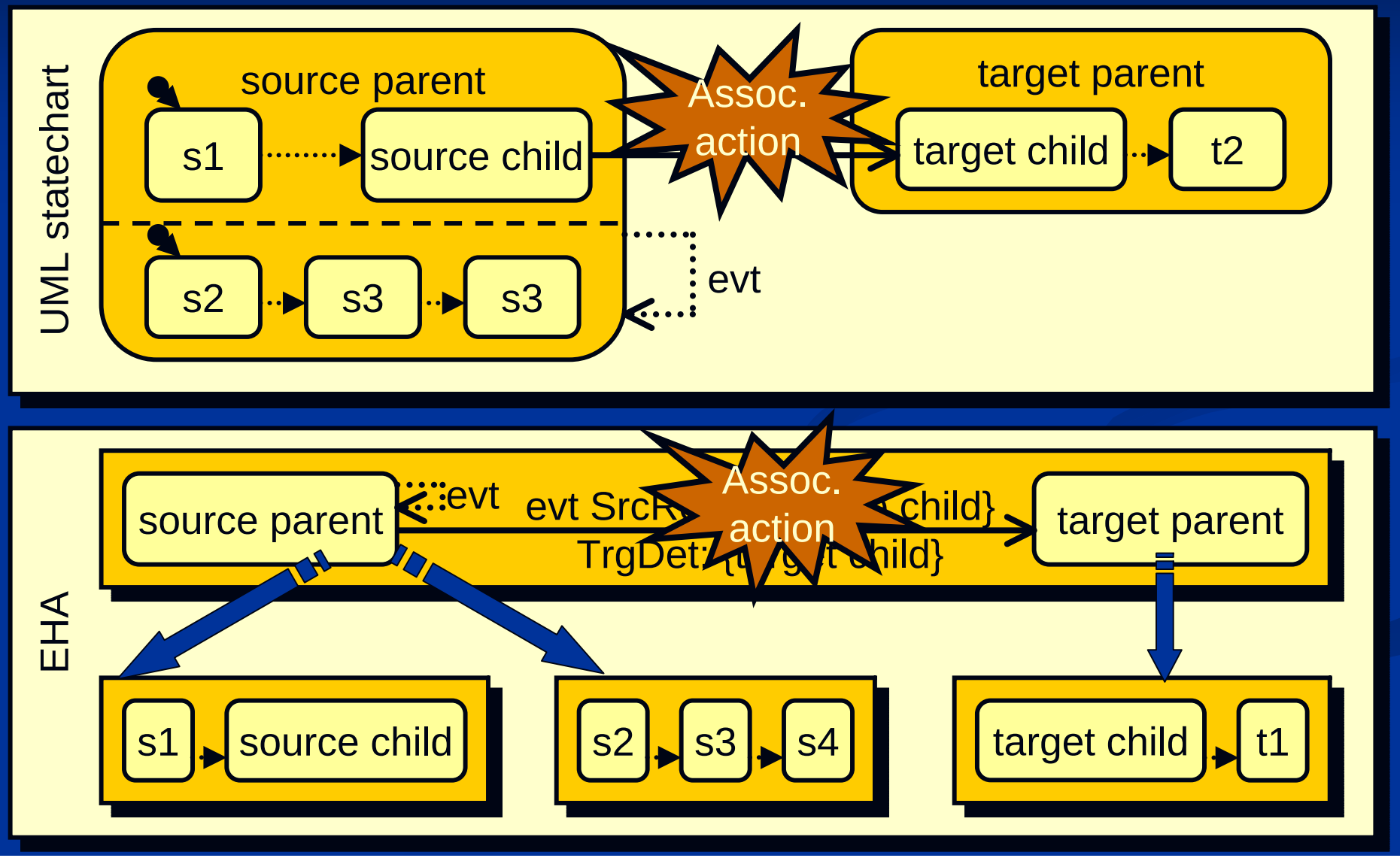

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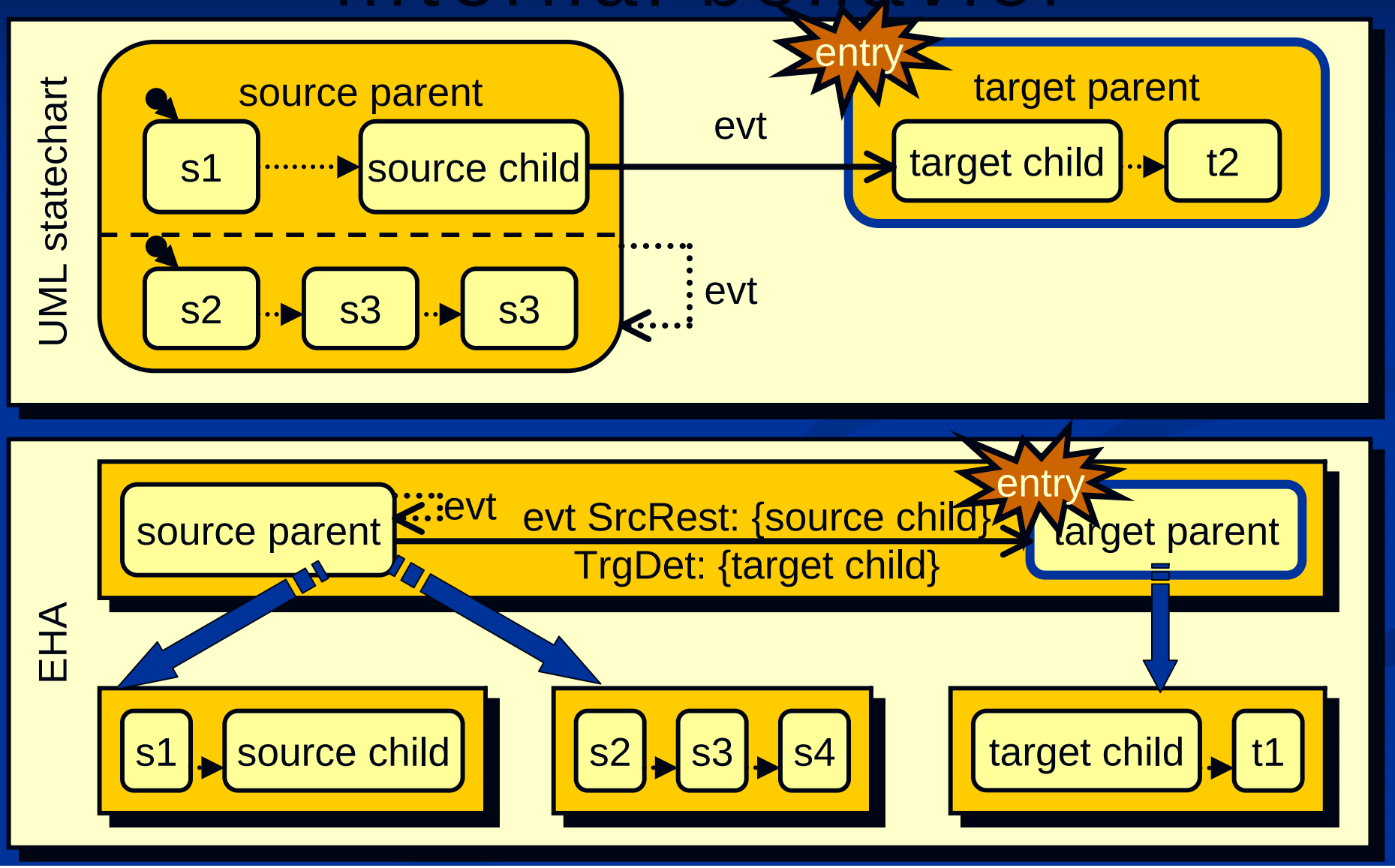

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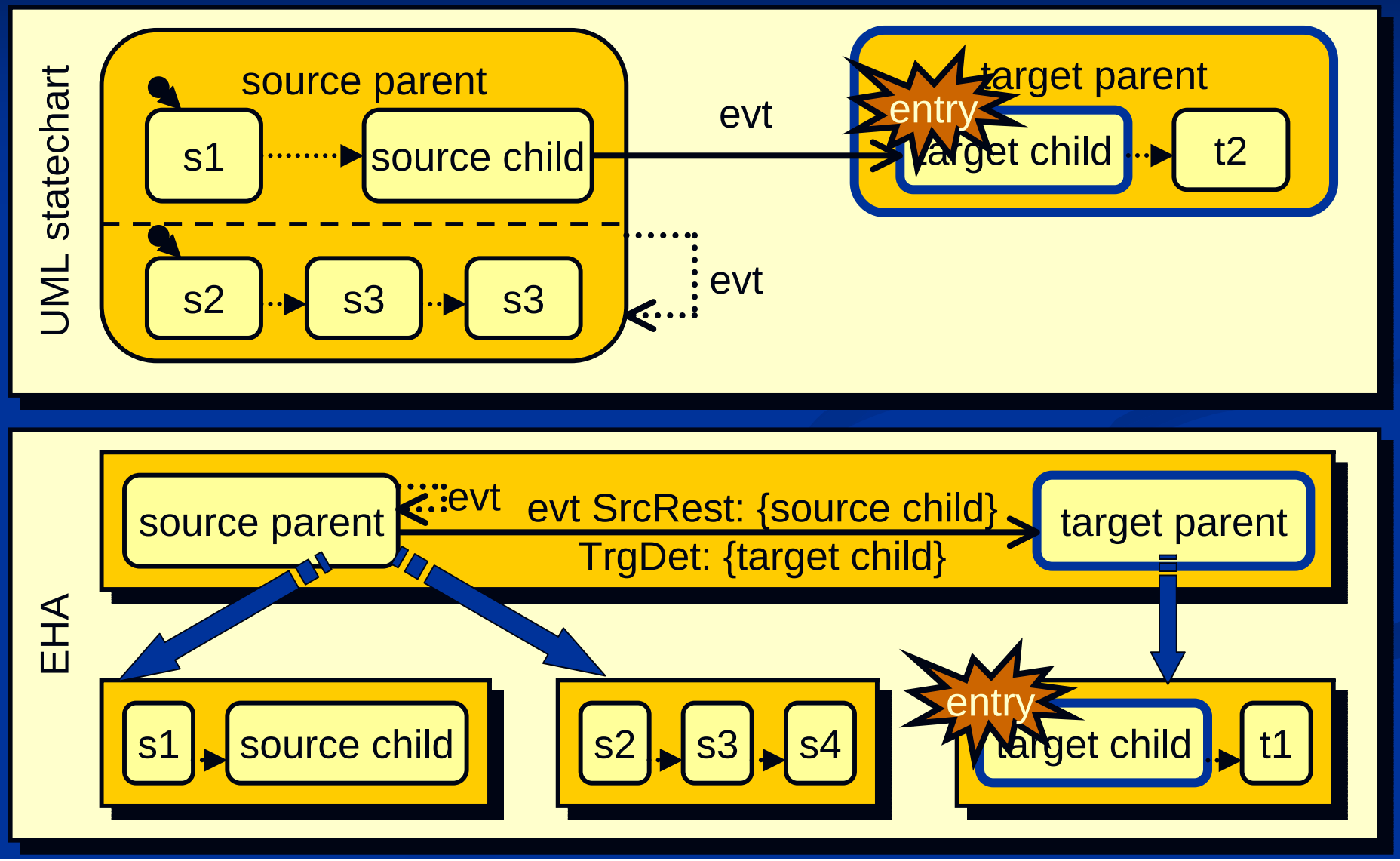

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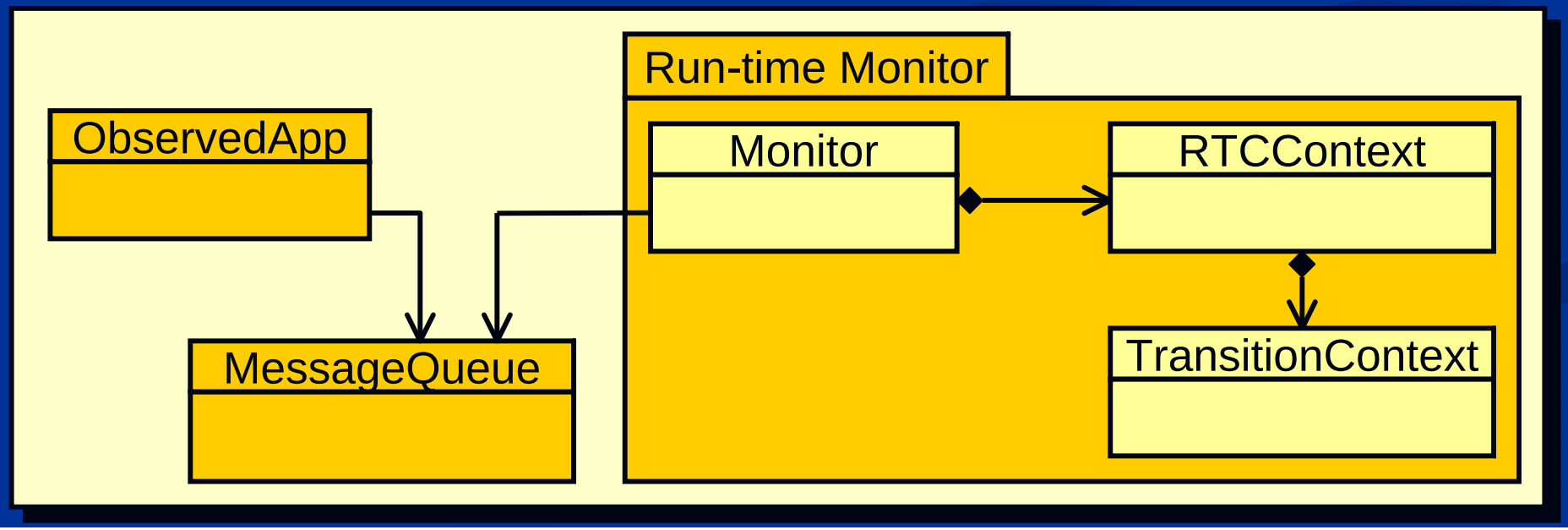
Checking the internal behavior

- Structural decomposition:
  - *Run-to-completion* and *transition contexts*
- Specification of contexts:
  - Protocol state machines (statecharts)



Checking the internal behavior

- Structural decomposition:
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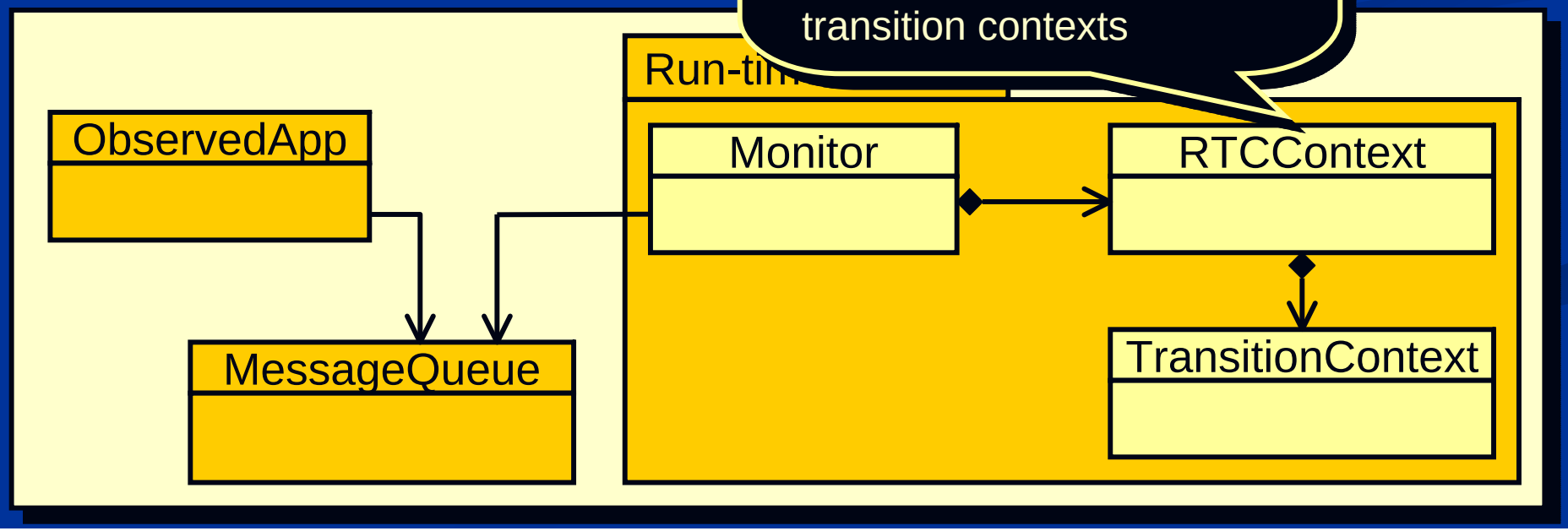
Run-to-completion context
- Initialization
- Start and finish of event processing
- Dispatching messages to transition contexts



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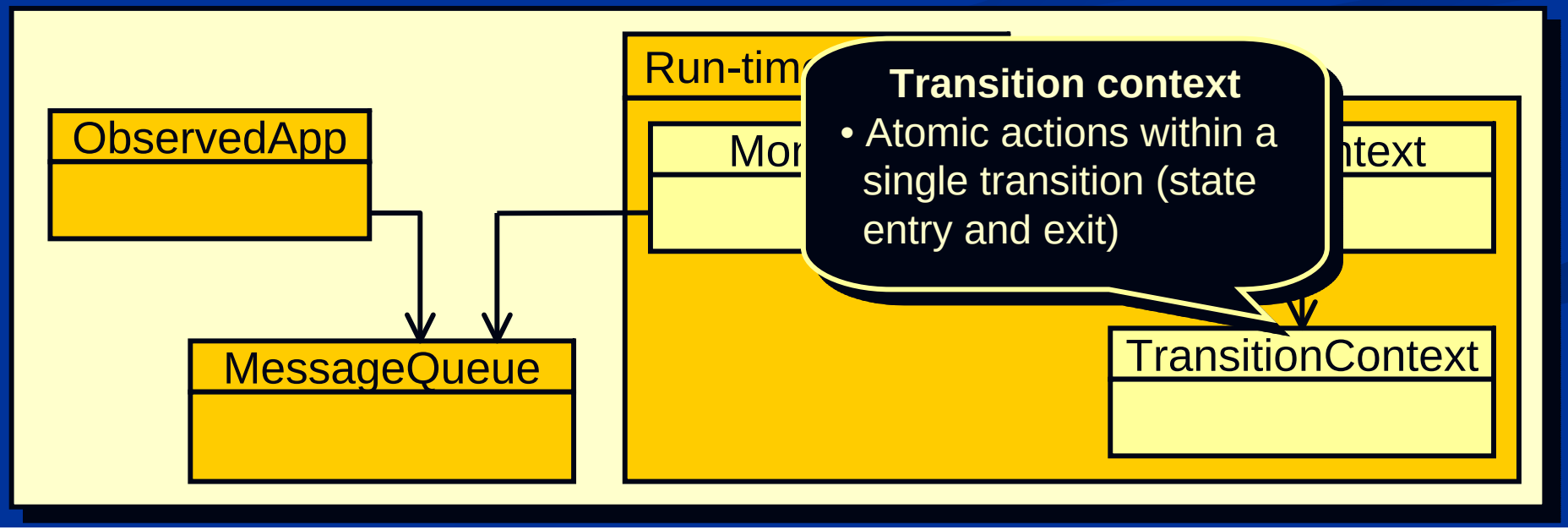

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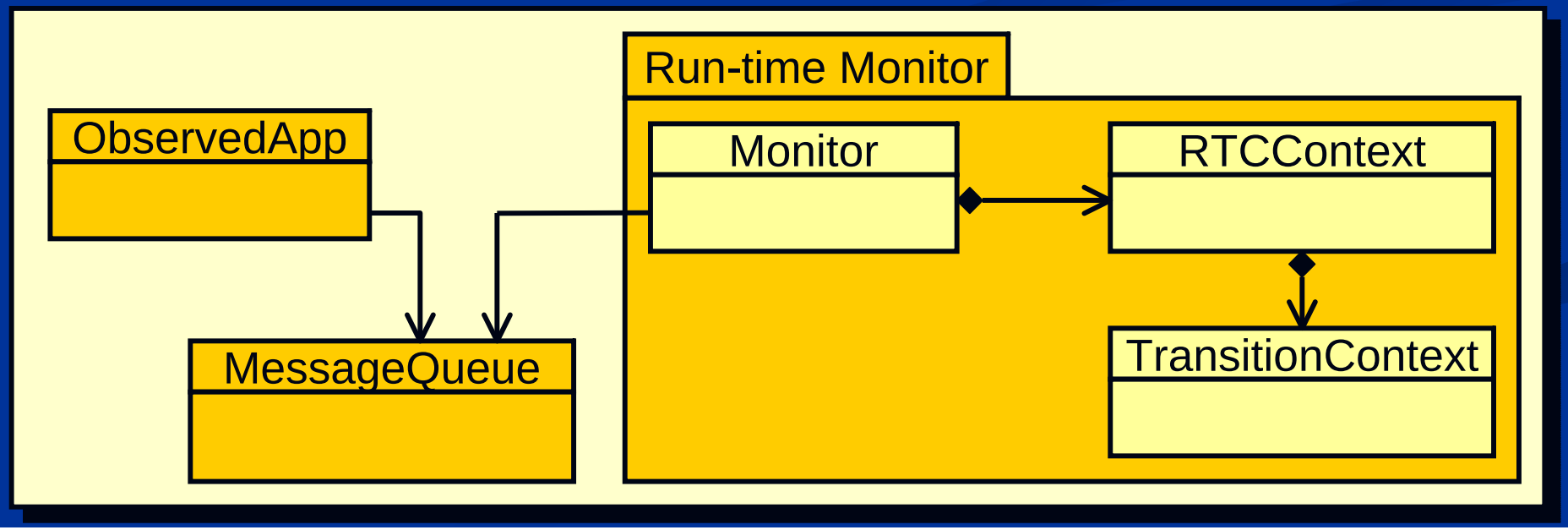

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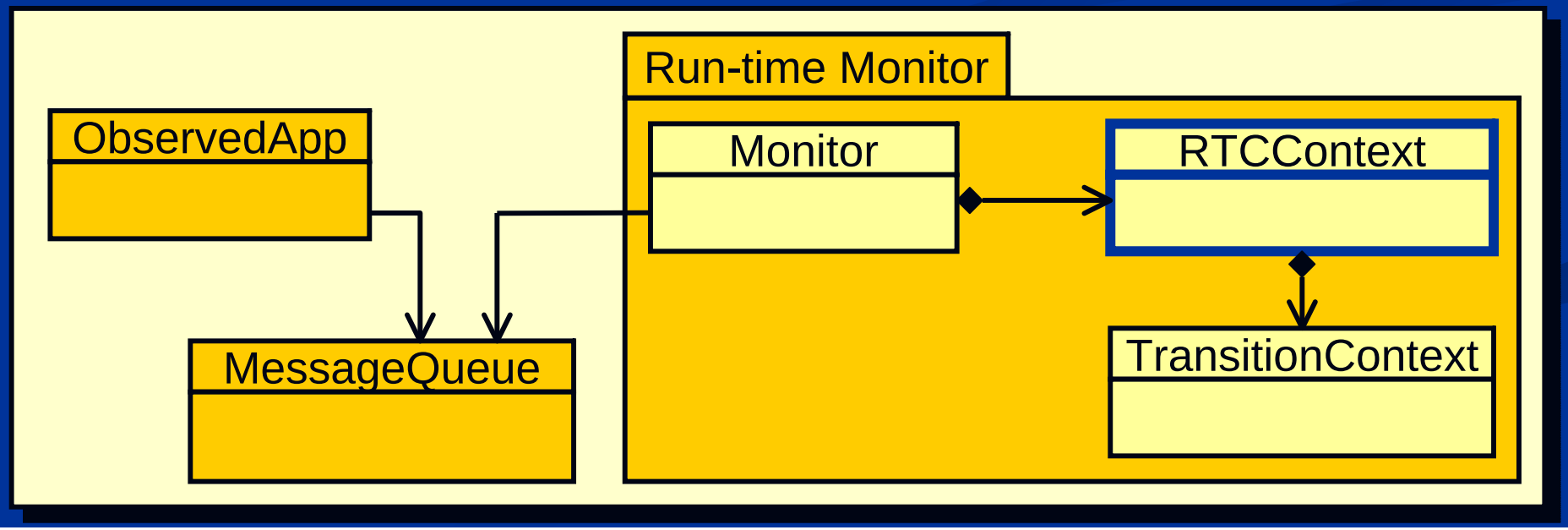
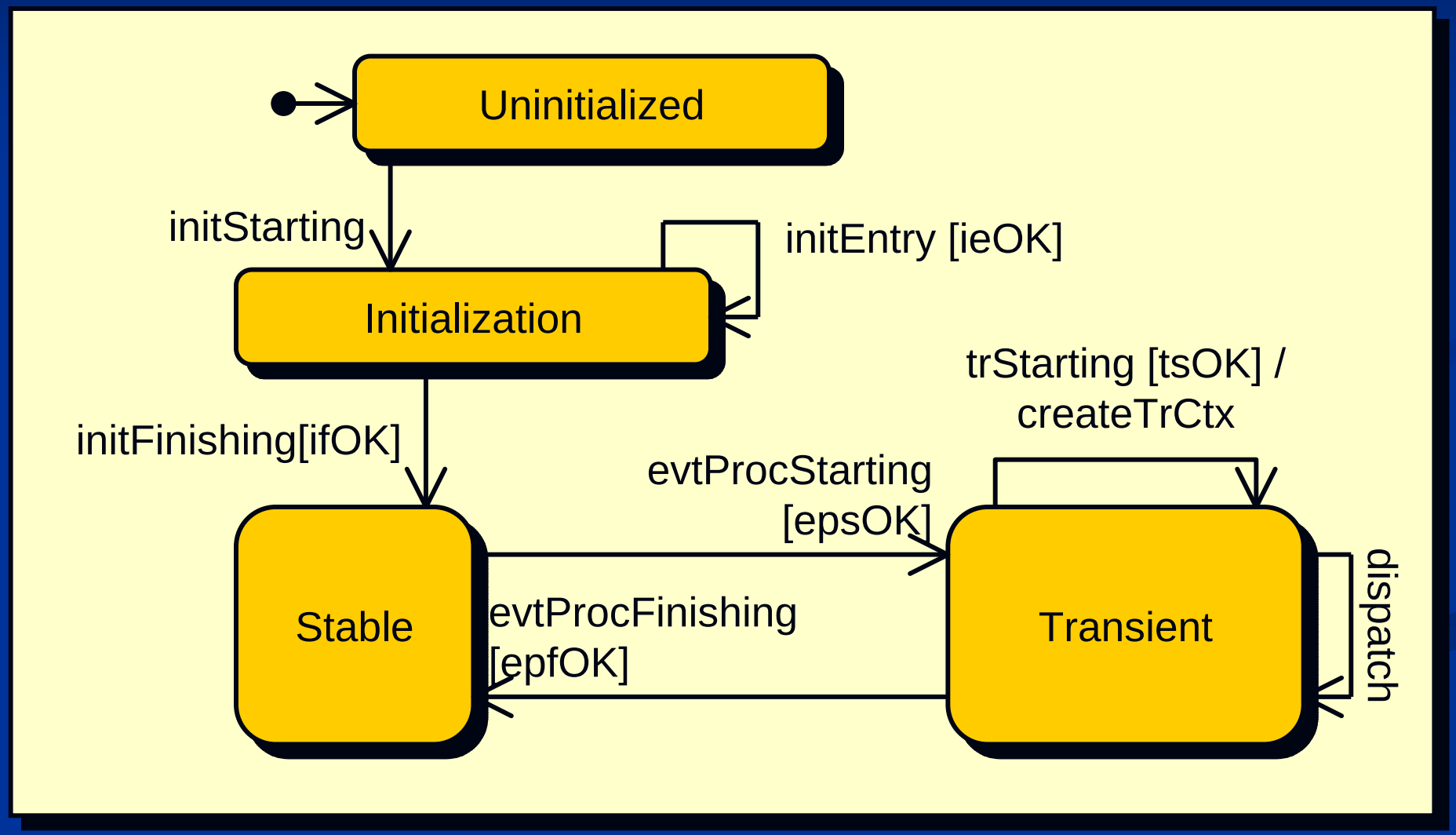
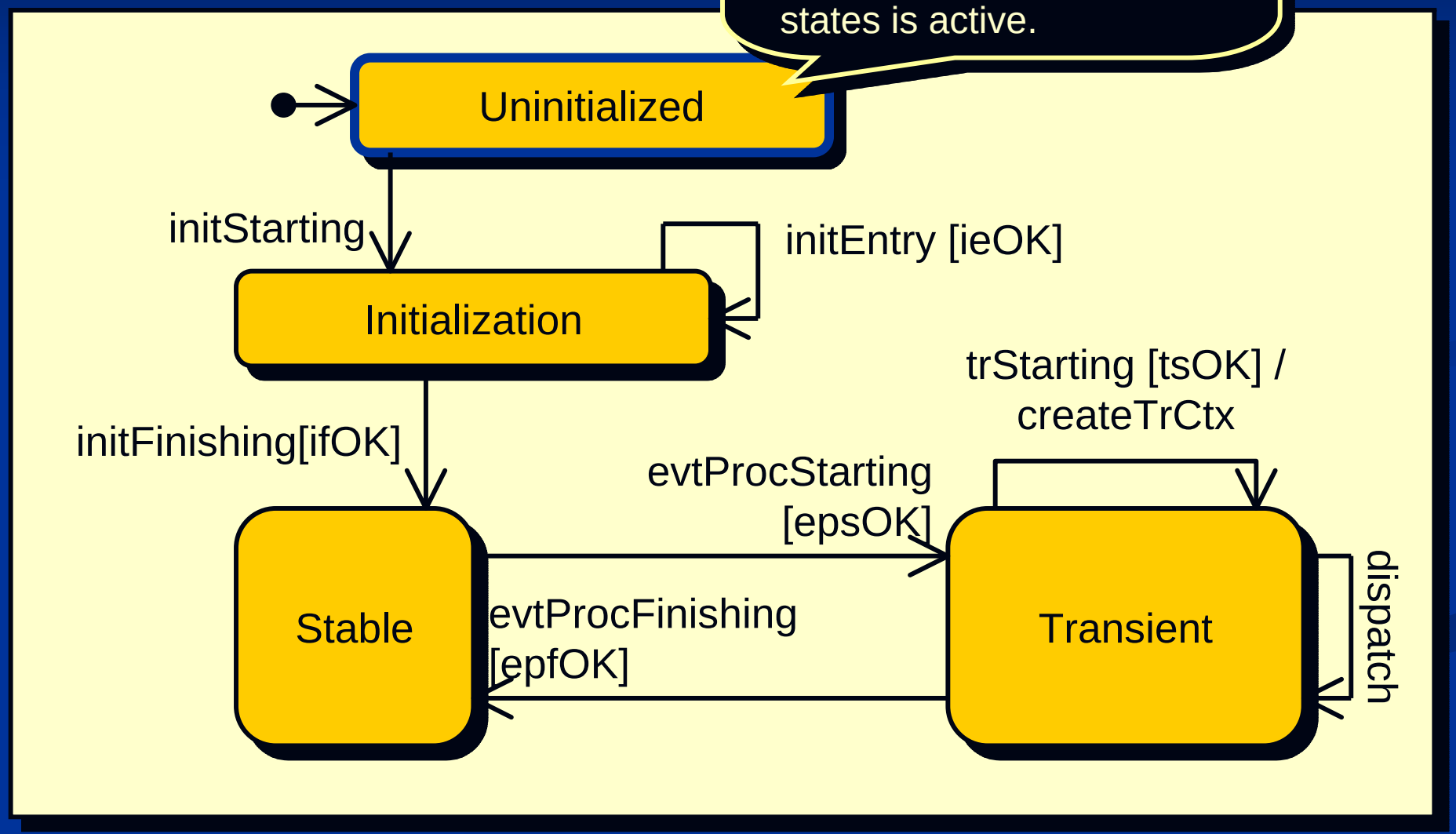


Run-to-completion context



Run-to-compl t

Before initialization
- The state configuration of the observed application is inconsistent, none of the states is active.



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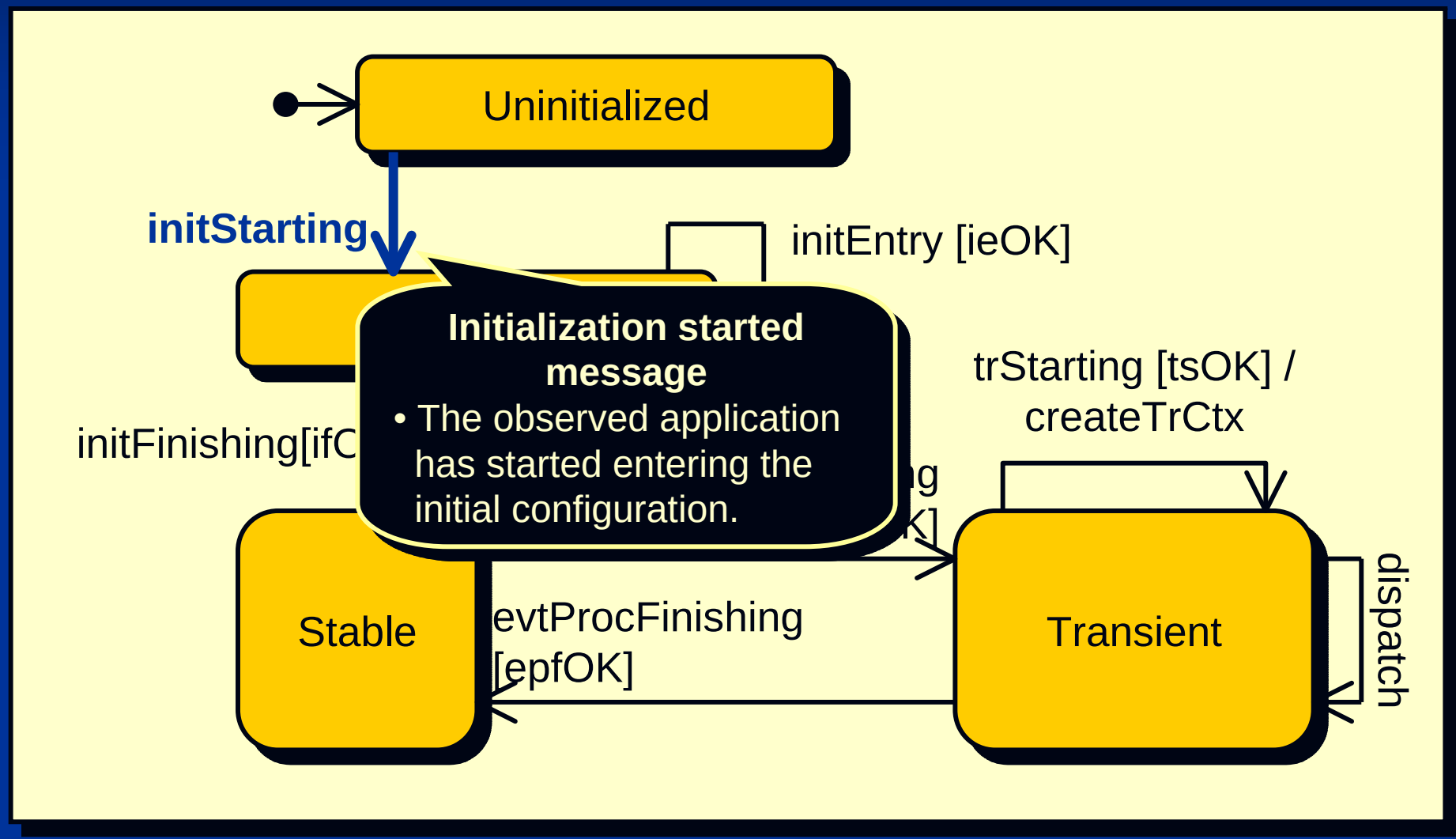

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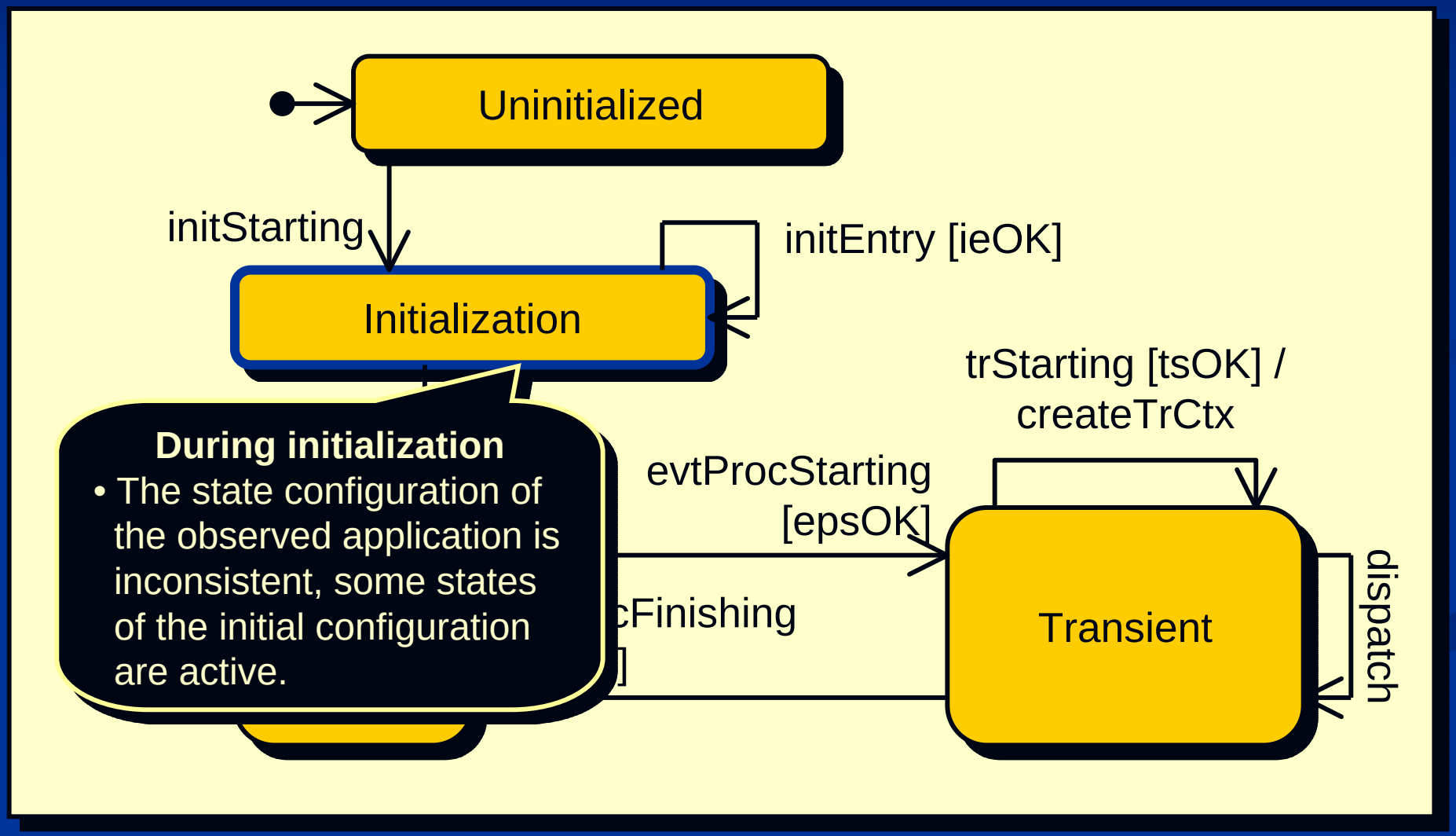
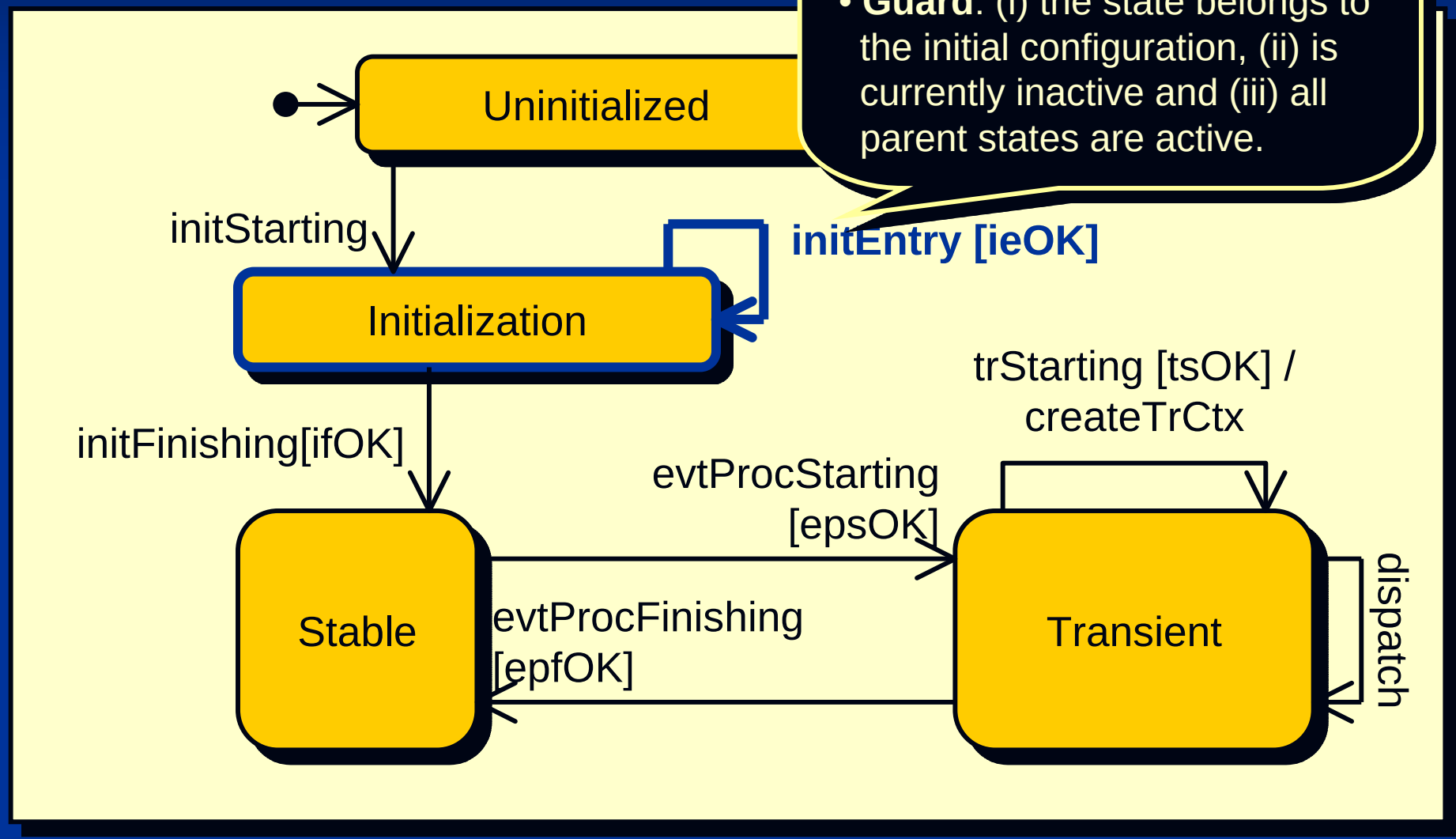


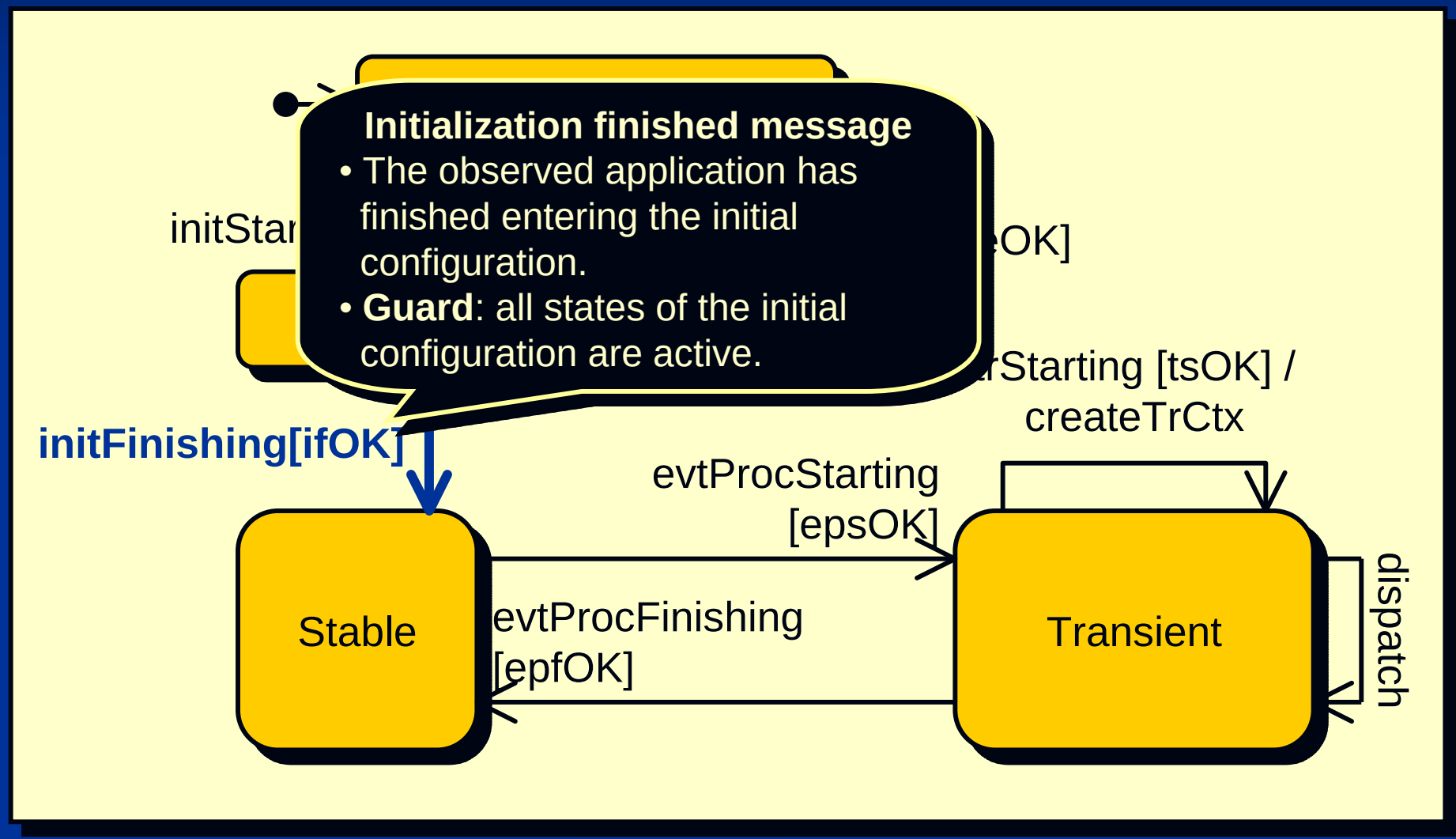
Run-to-complet

Entry during initialization

- The observed application has entered a state.
- **Guard**: (i) the state belongs to the initial configuration, (ii) is currently inactive and (iii) all parent states are active.



Run-to-completion context



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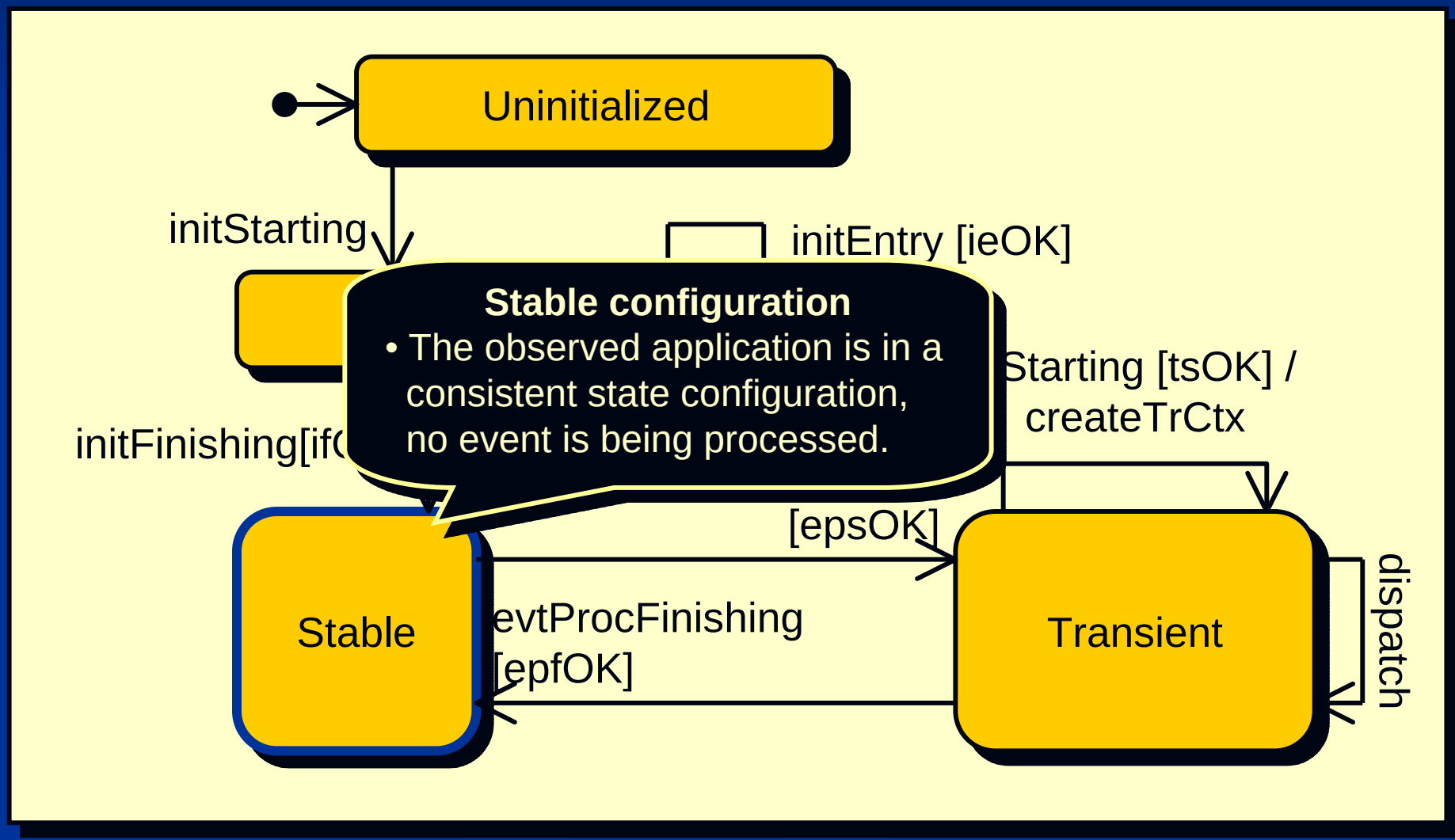

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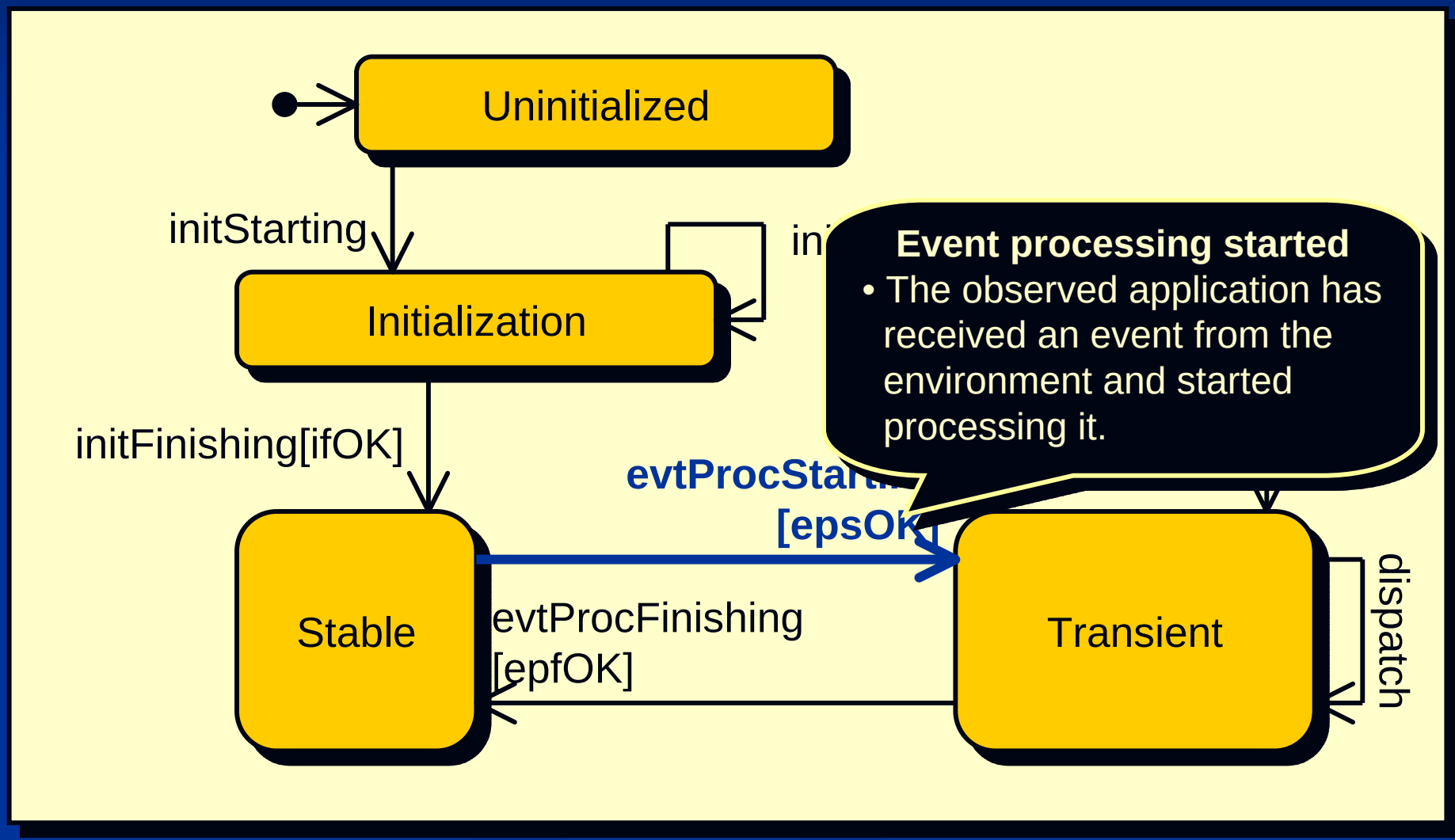

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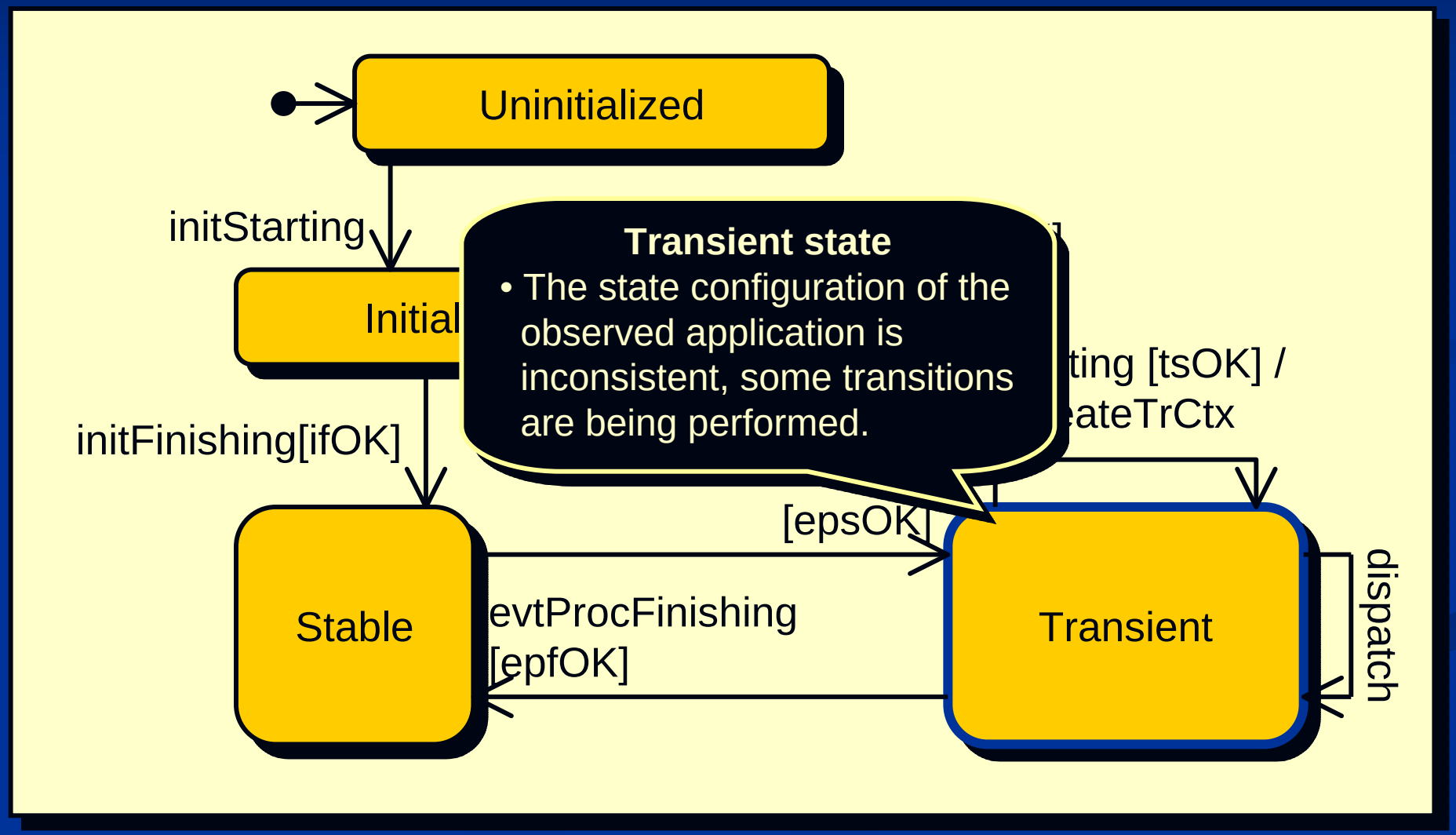
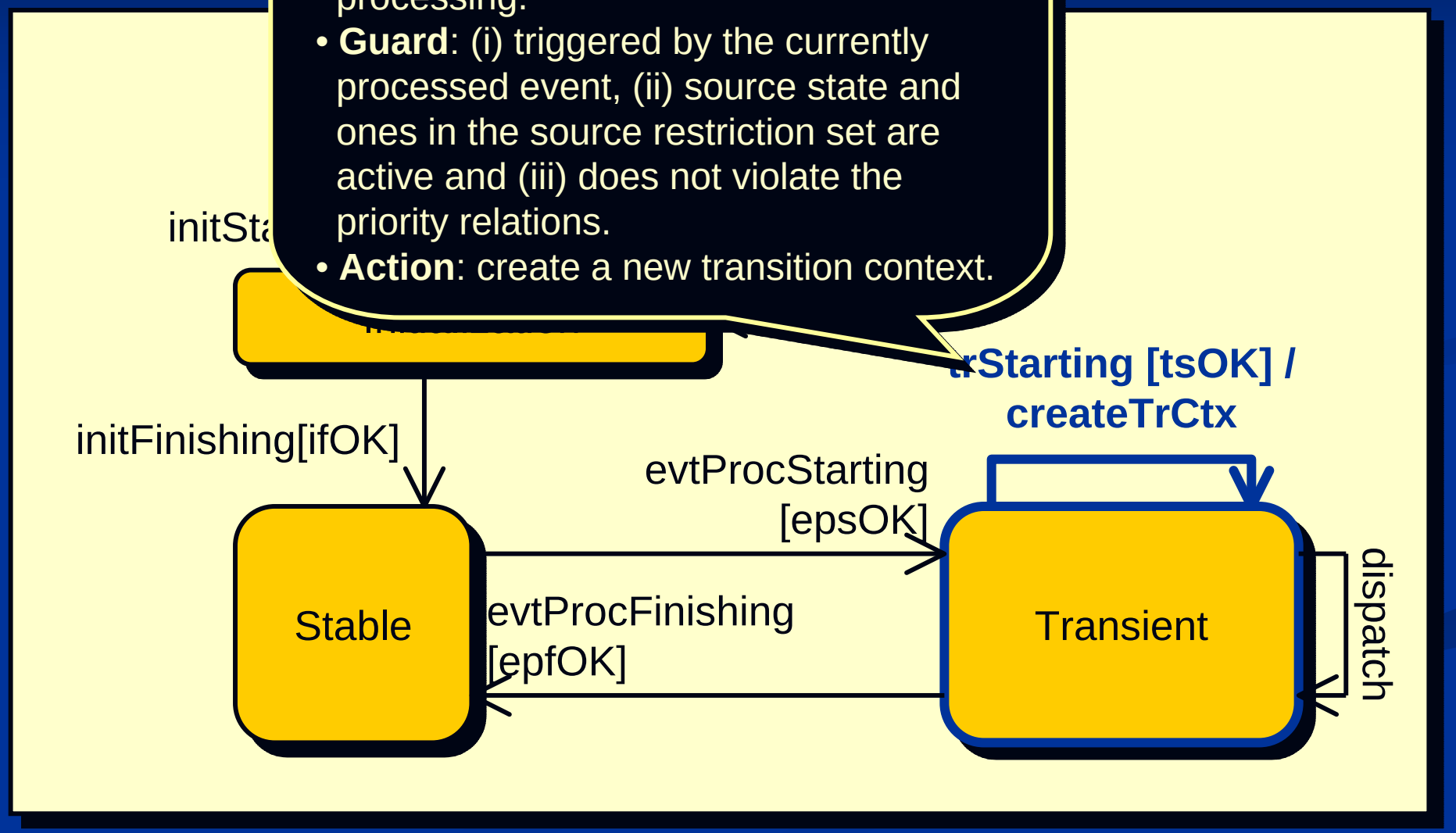


Run ontext

Transition selected for firing

- The observed application has selected a transition to be fired during the event processing.
- **Guard**: (i) triggered by the currently processed event, (ii) source state and ones in the source restriction set are active and (iii) does not violate the priority relations.
- **Action**: create a new transition context.



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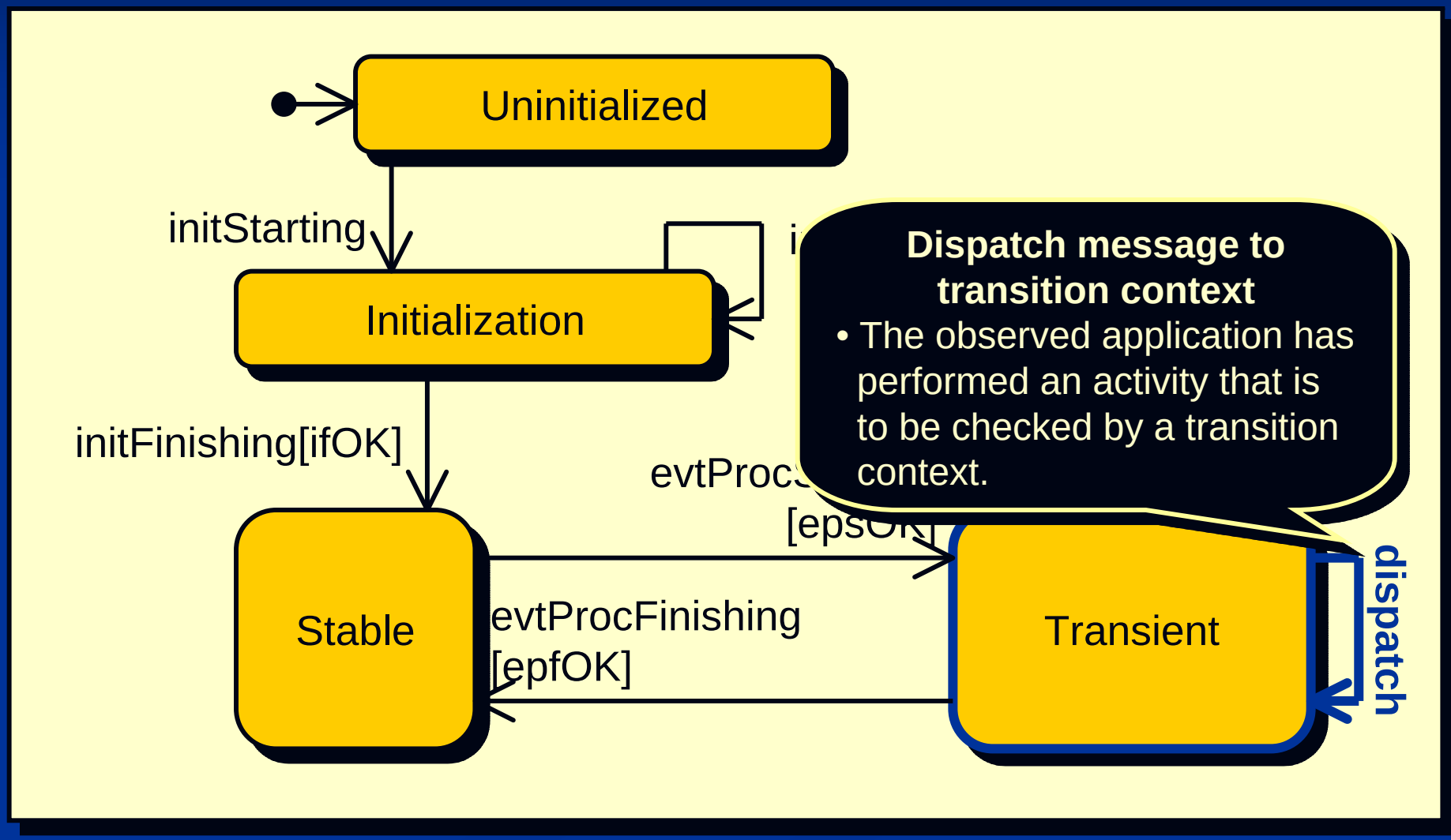

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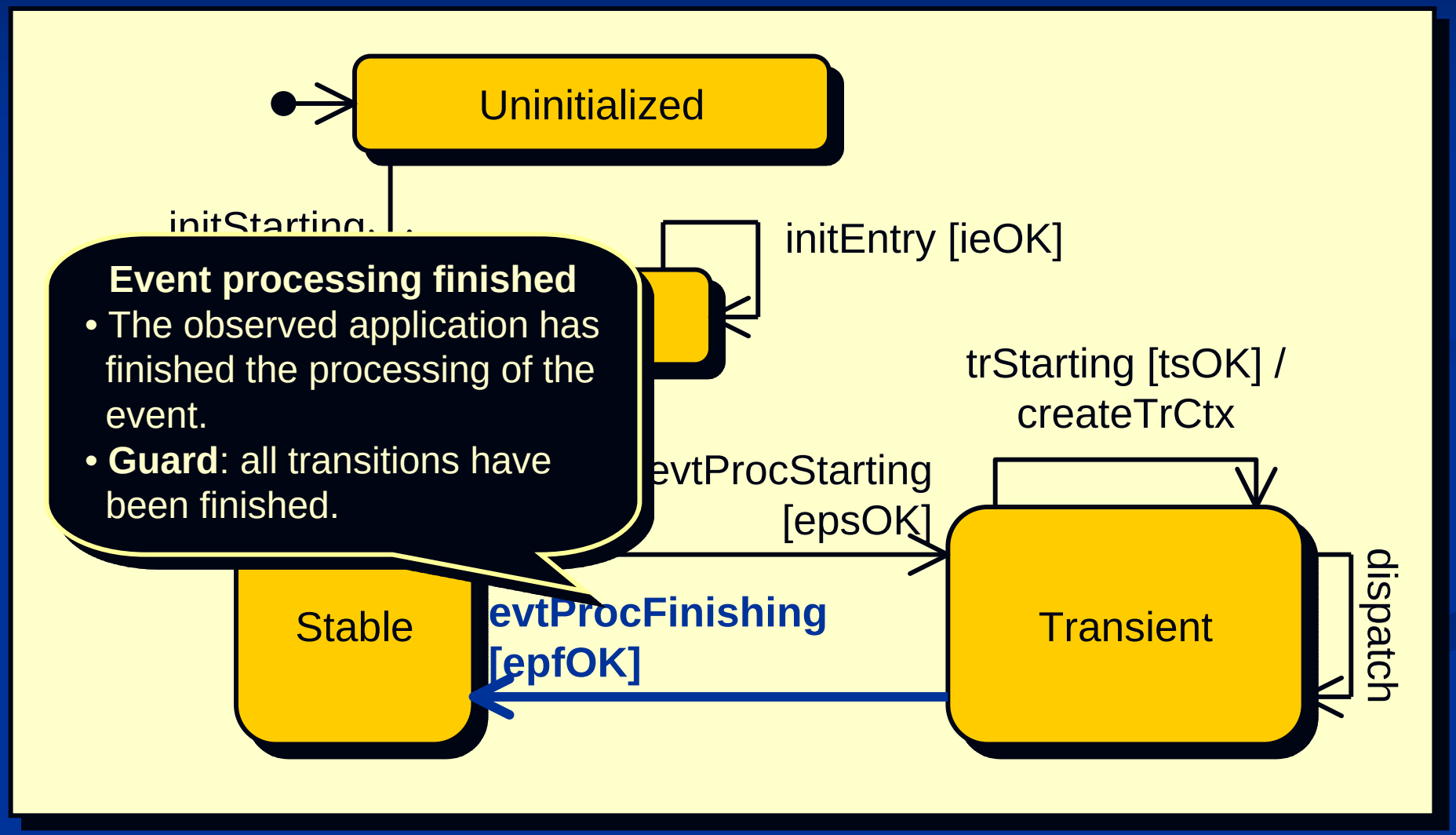

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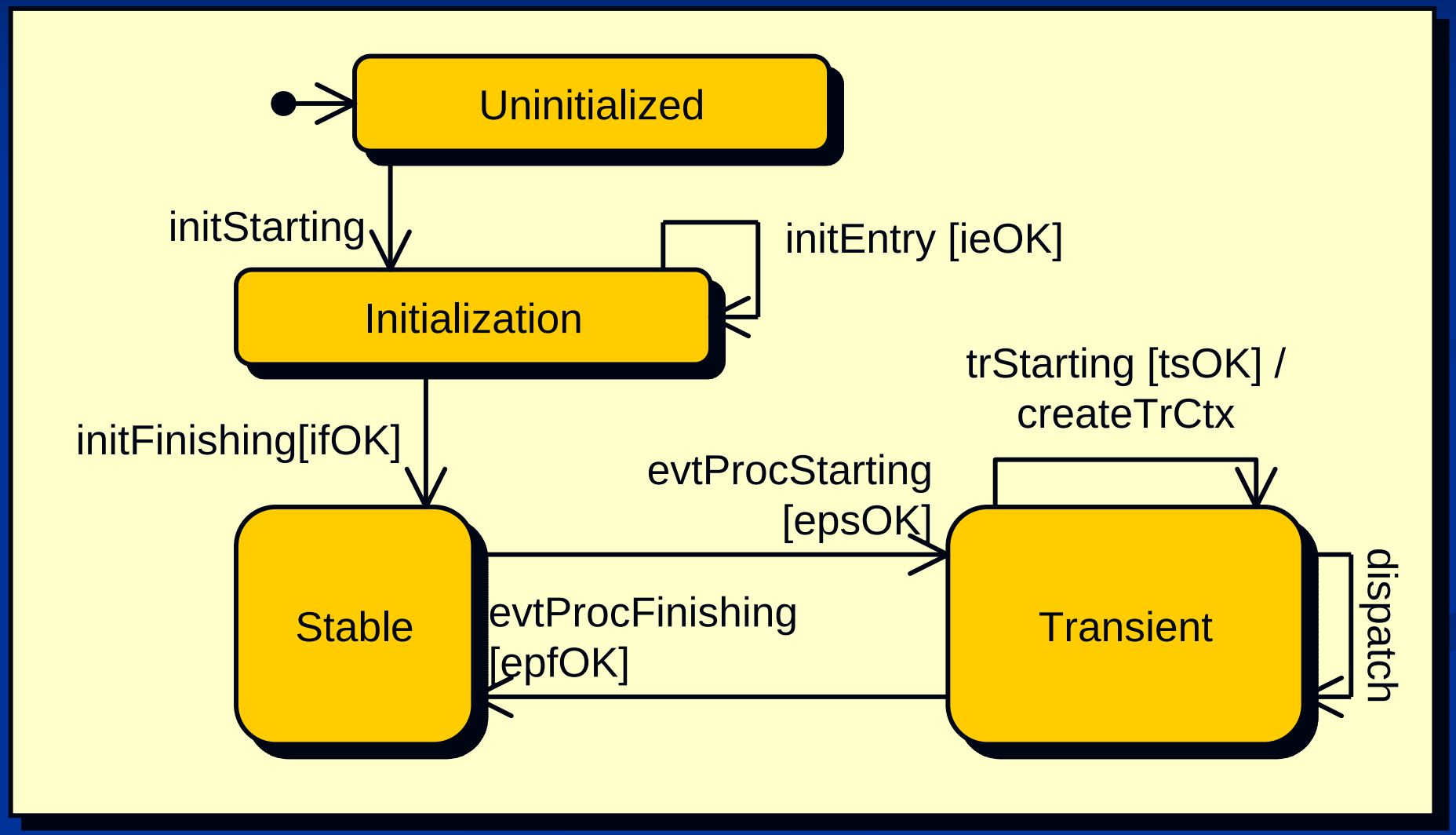

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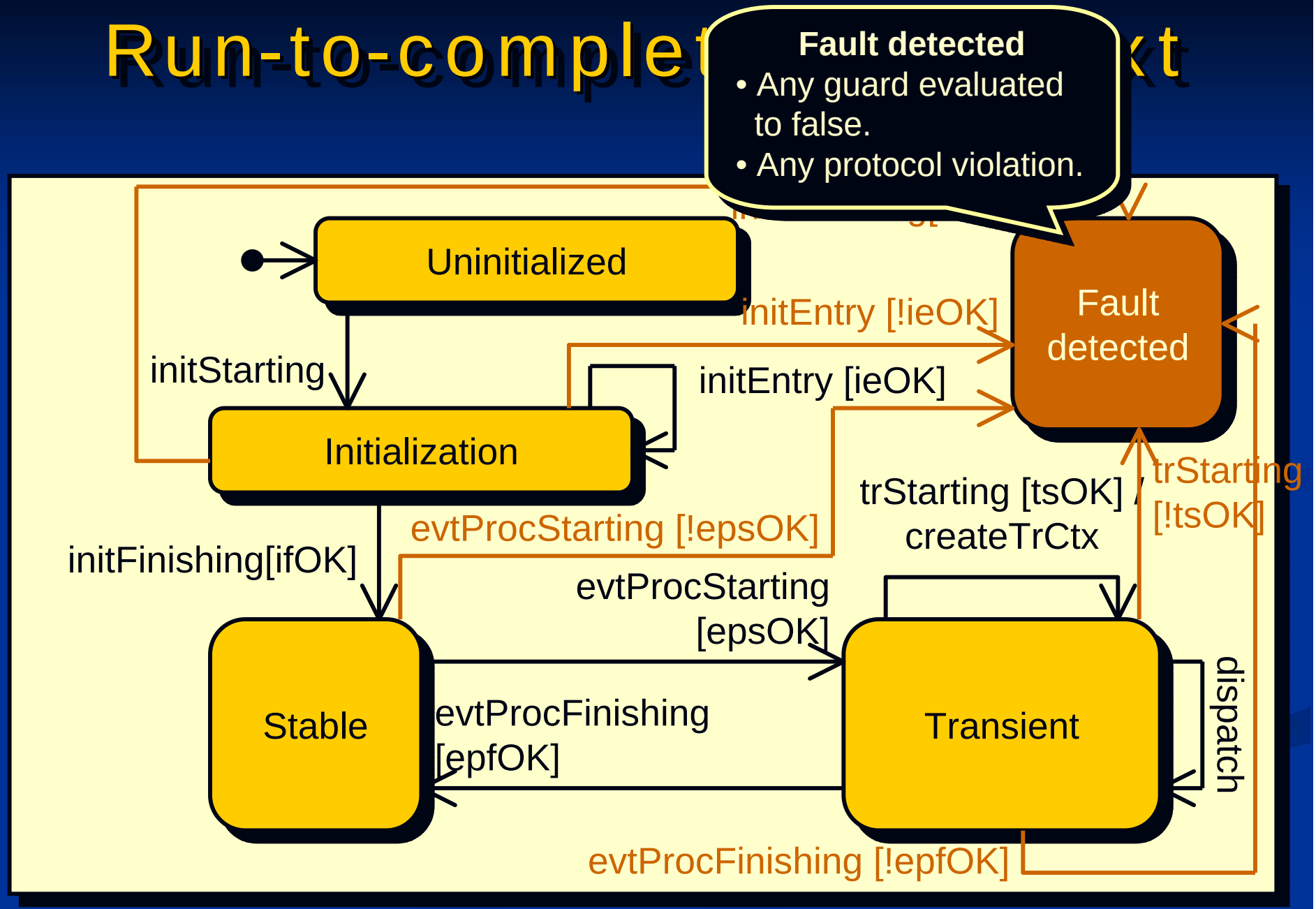

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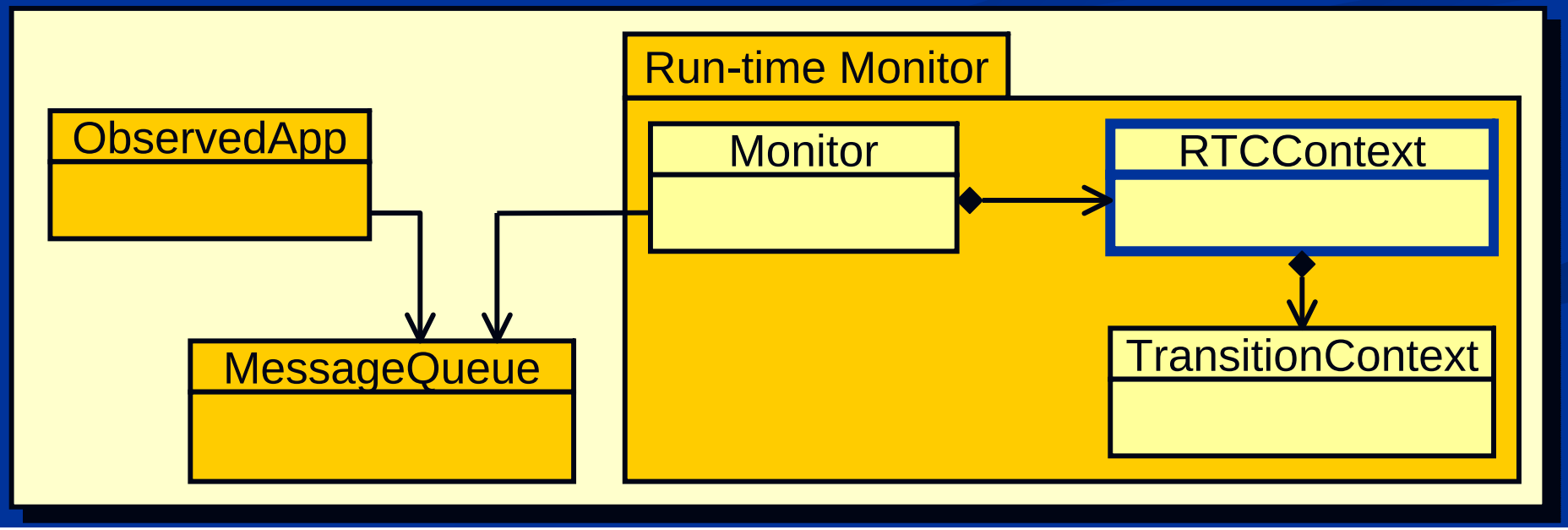

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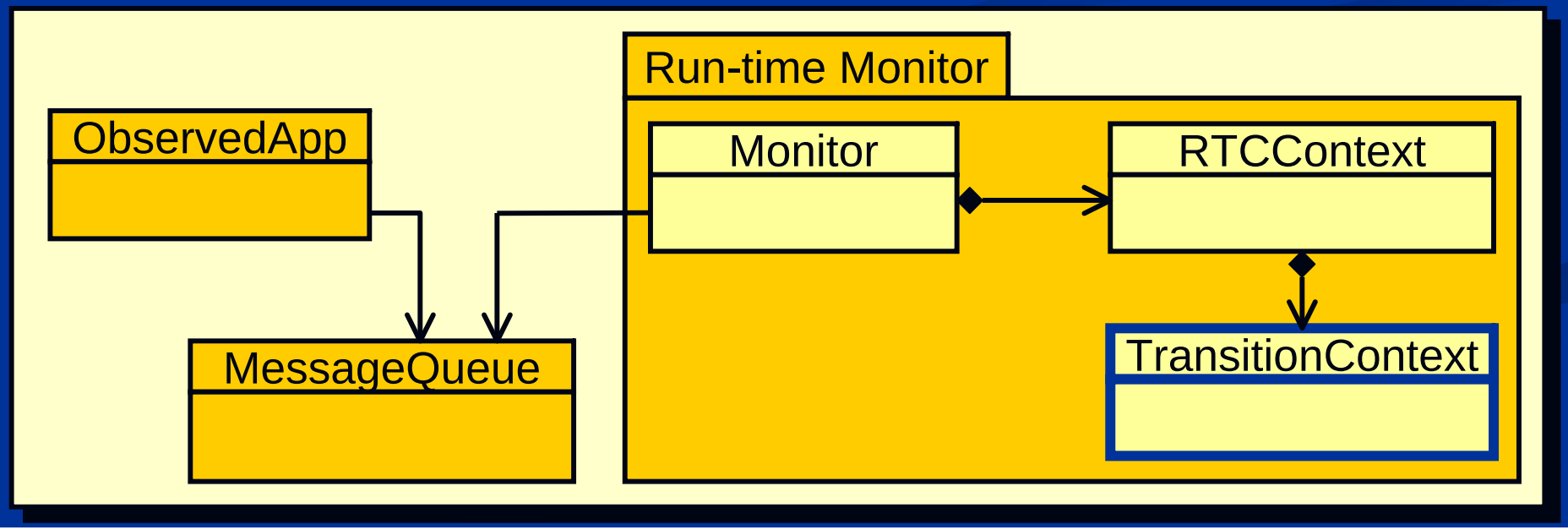
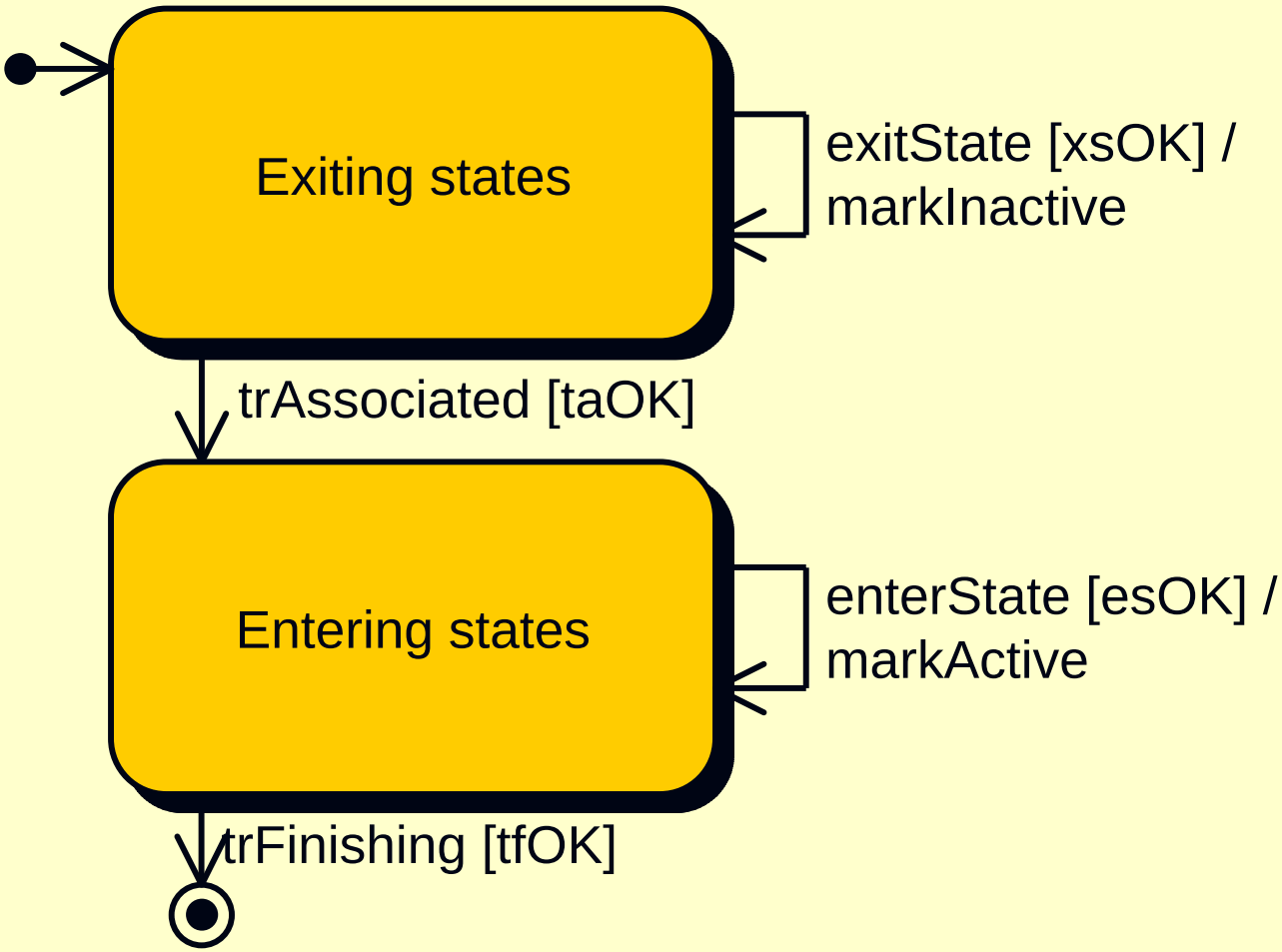


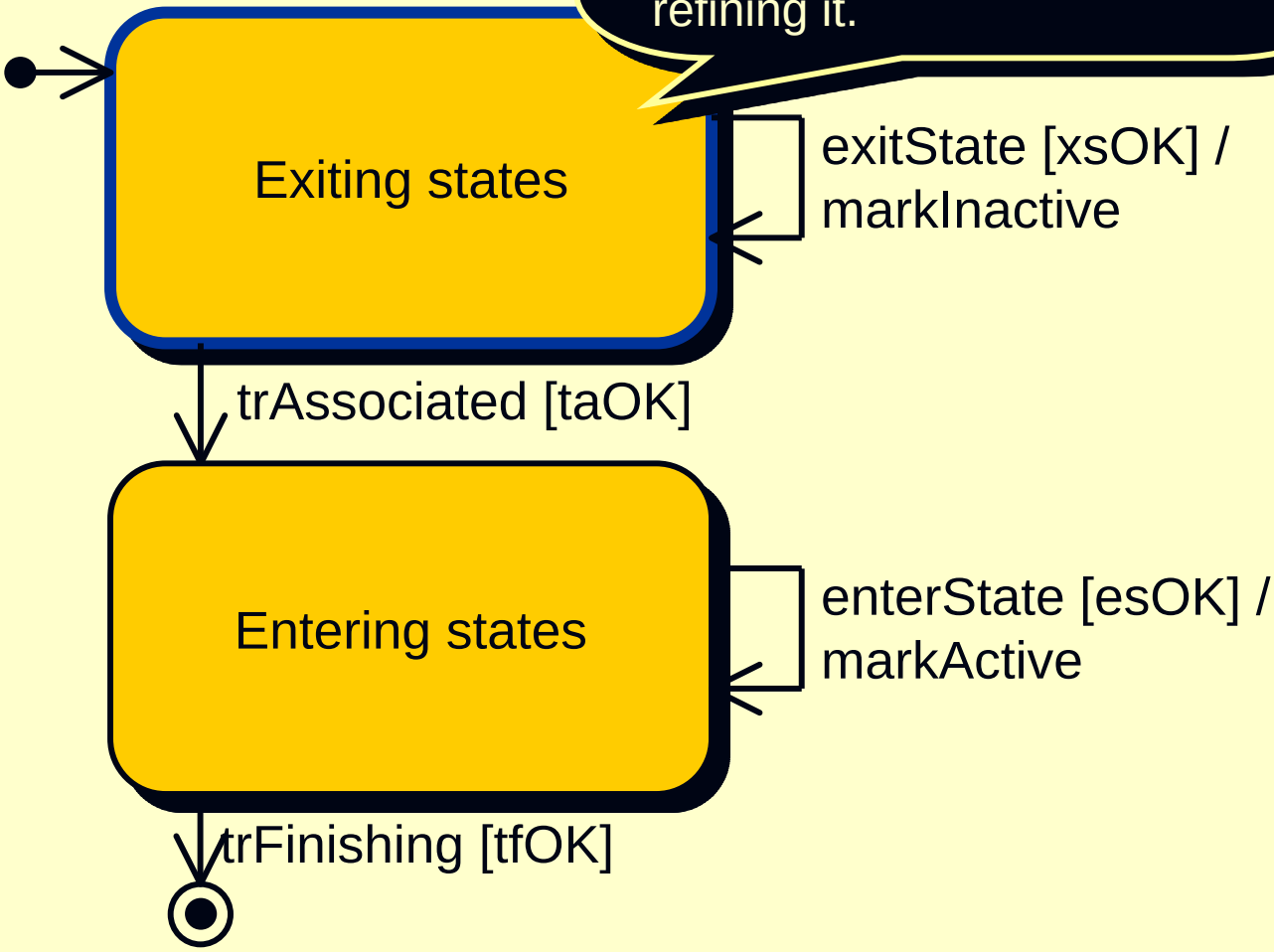
Transition context



Transit

Exiting states

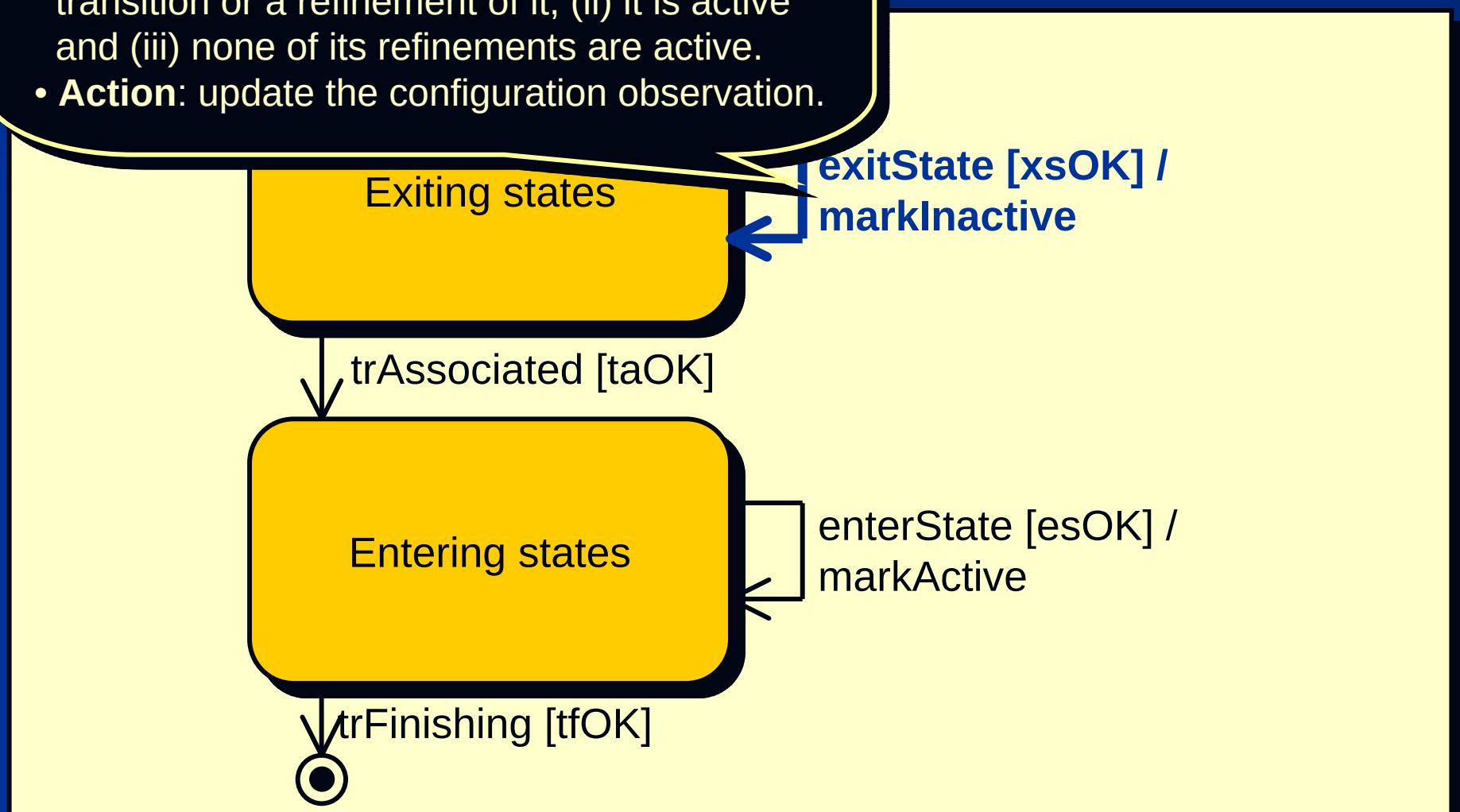
- The observed application is in the first phase of performing a transition: leaving the source state and all active states refining it.



ontext

State left

- The observed application has left a state during a transition.
- **Guard**: (i) the state is the source of the transition or a refinement of it, (ii) it is active and (iii) none of its refinements are active.
- **Action**: update the configuration observation.



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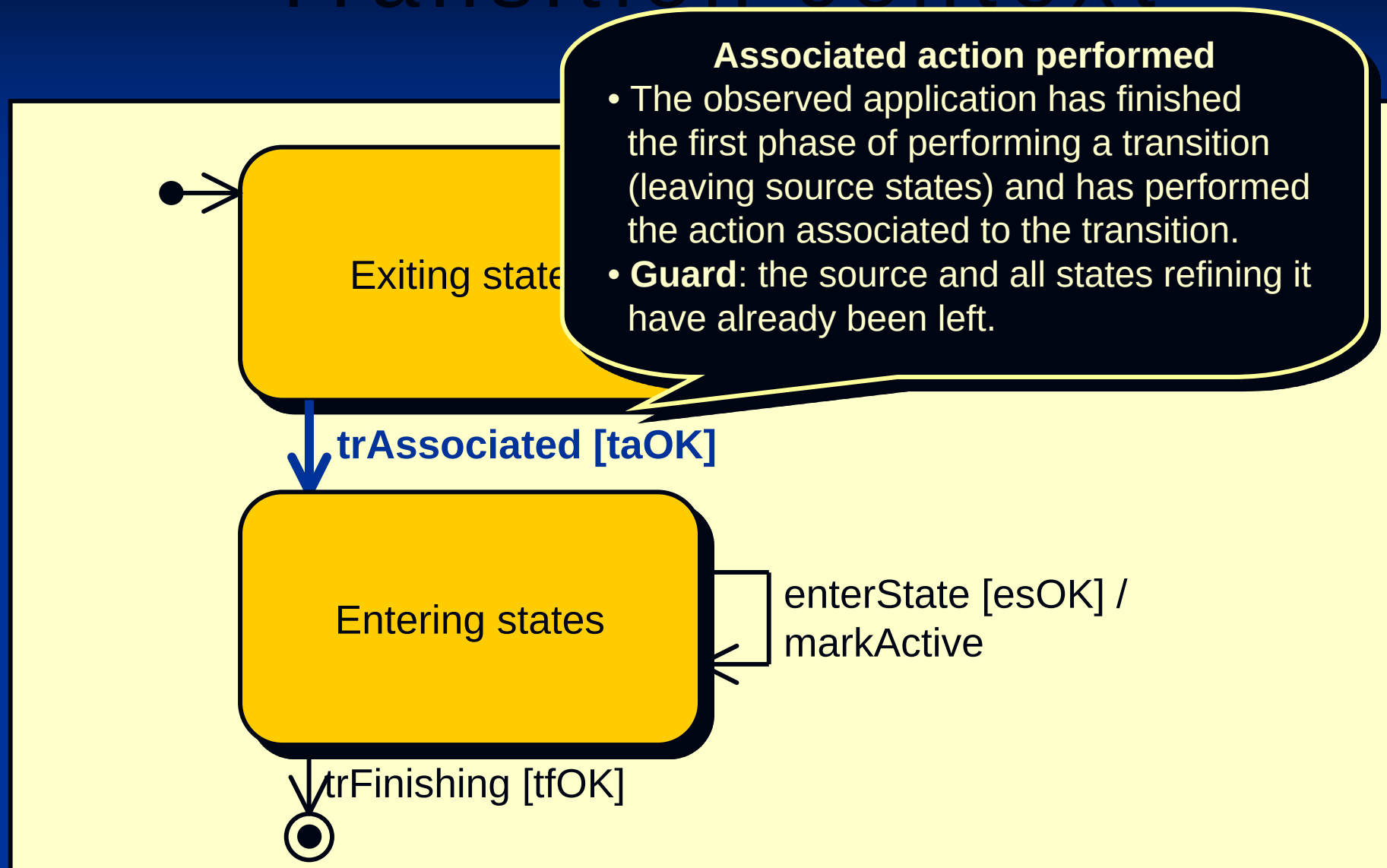

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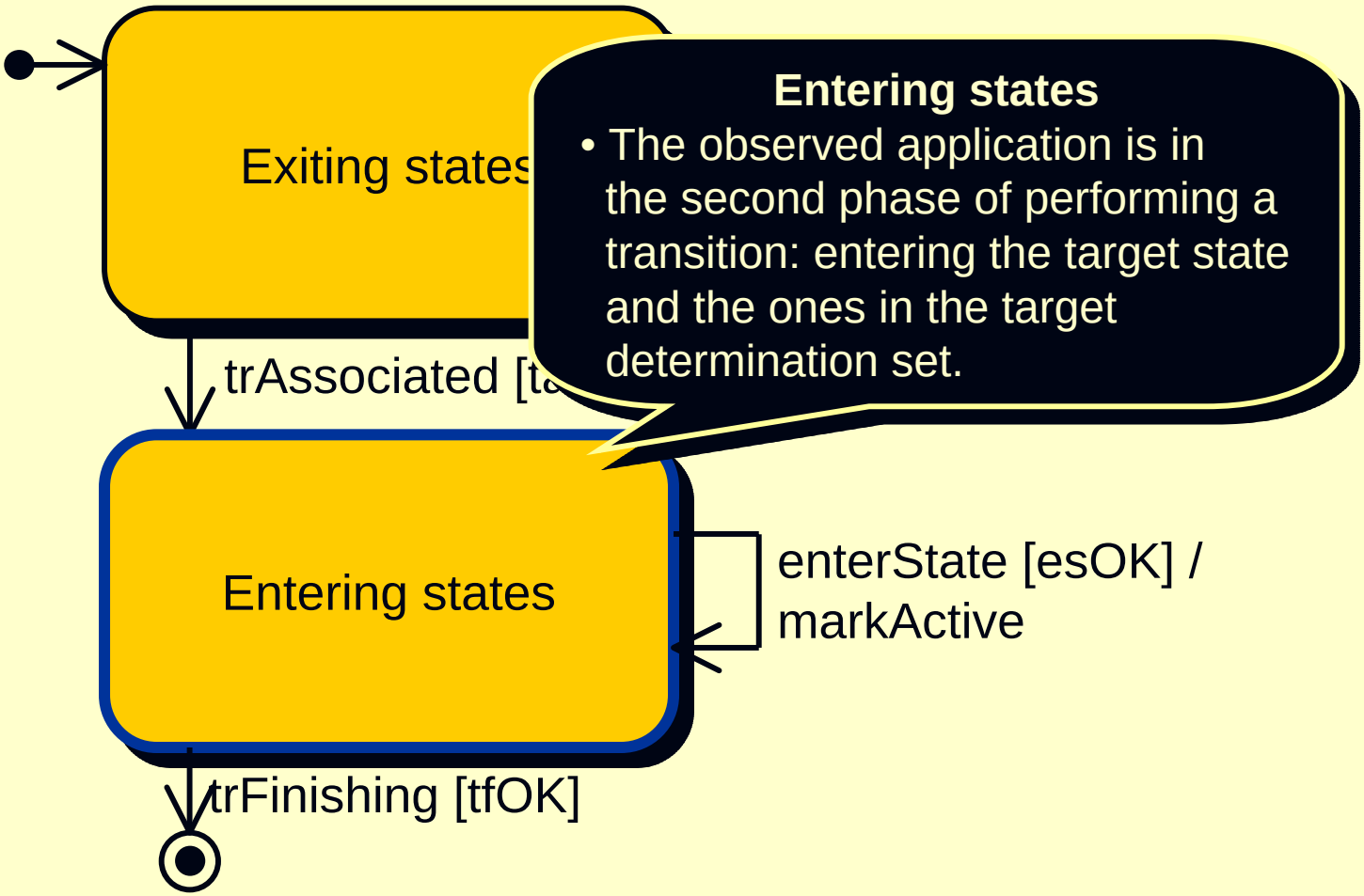
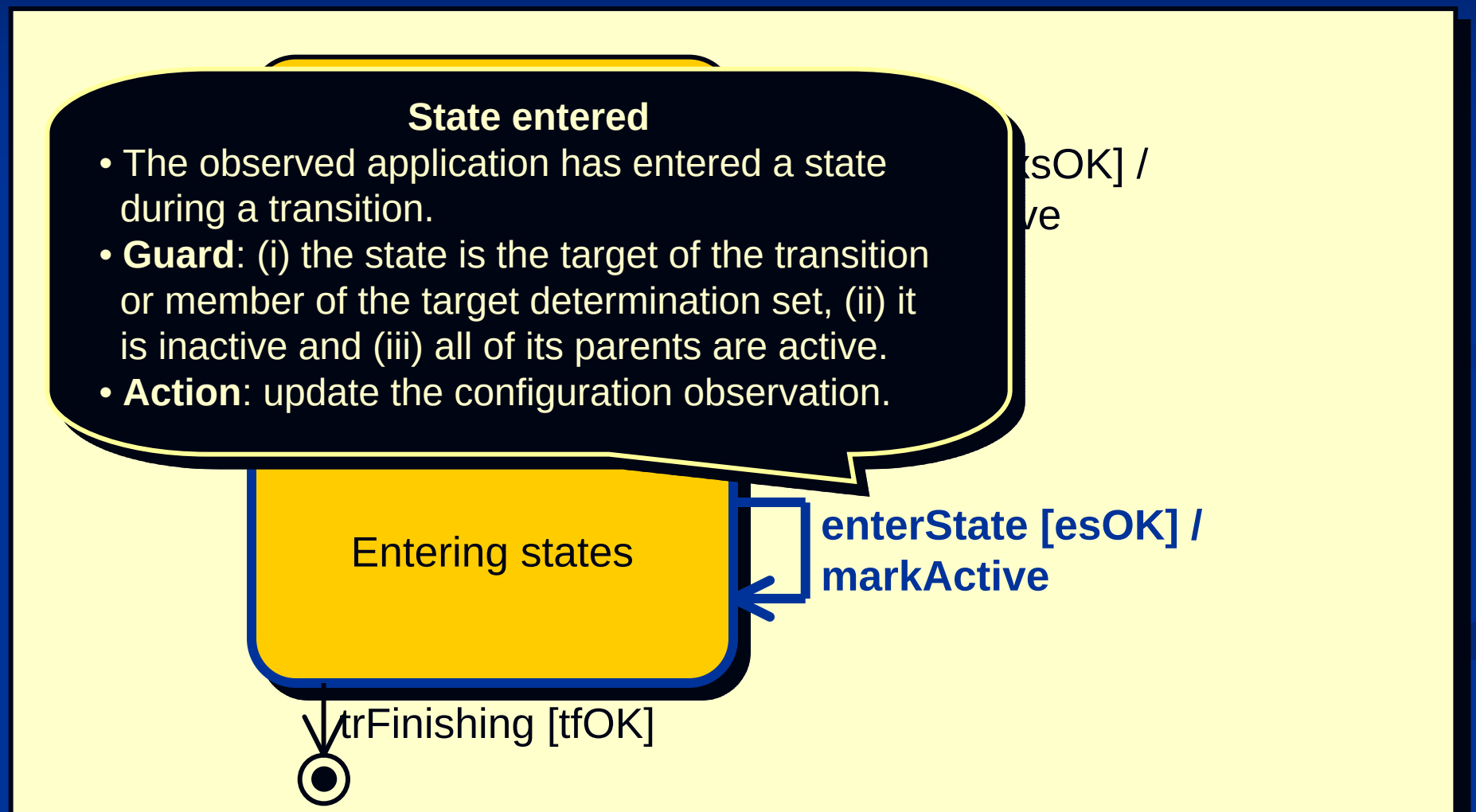
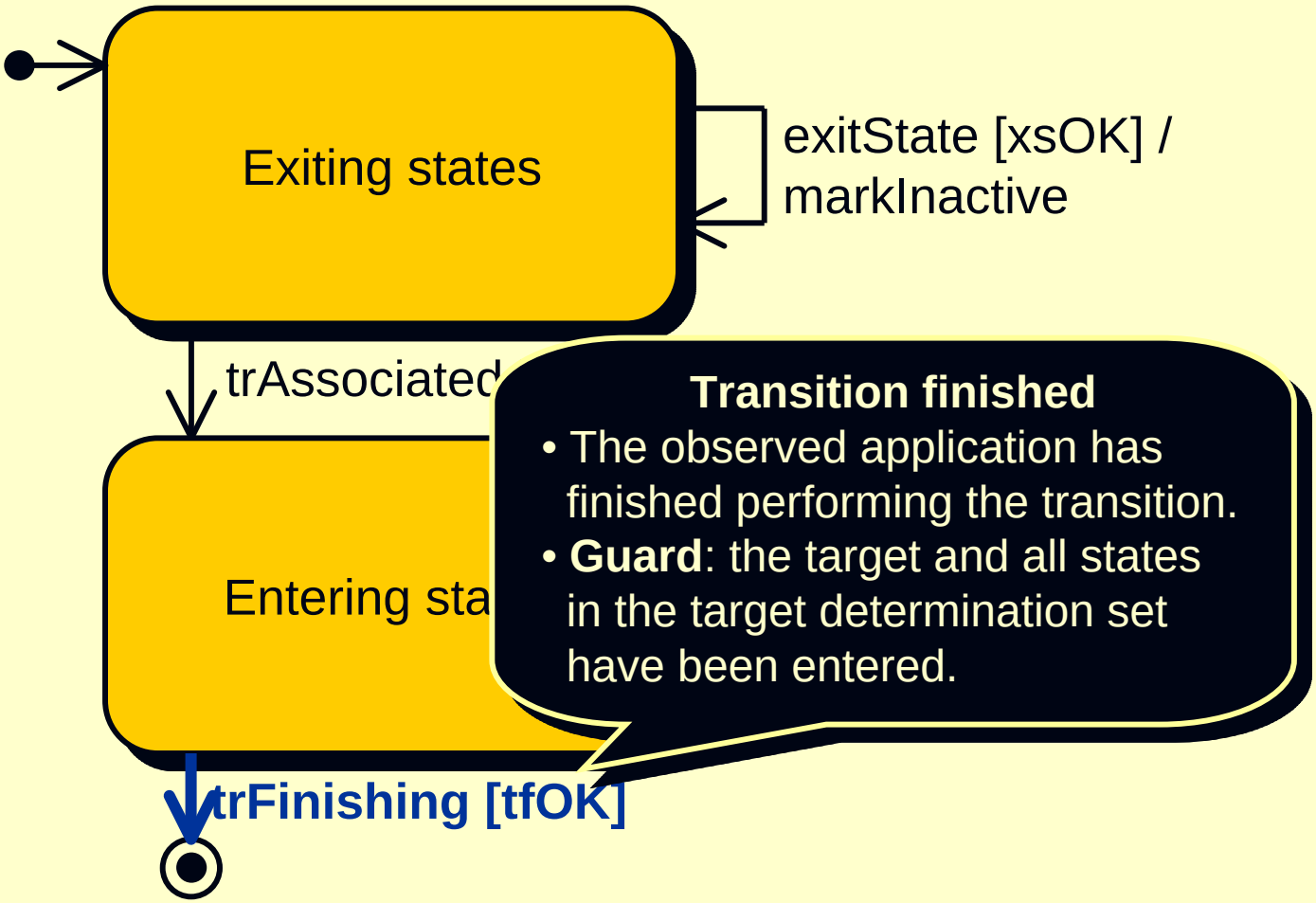


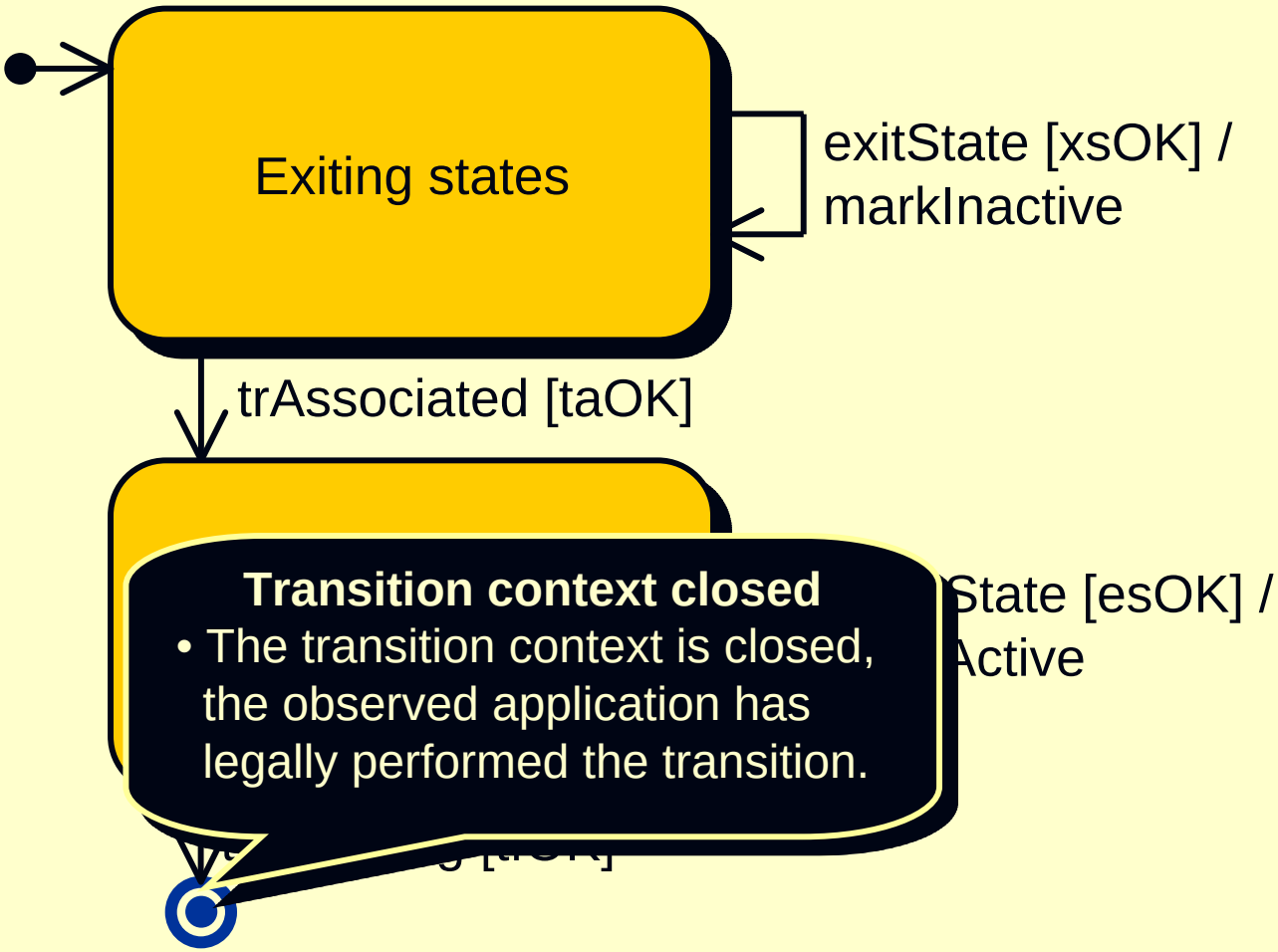
Transition context



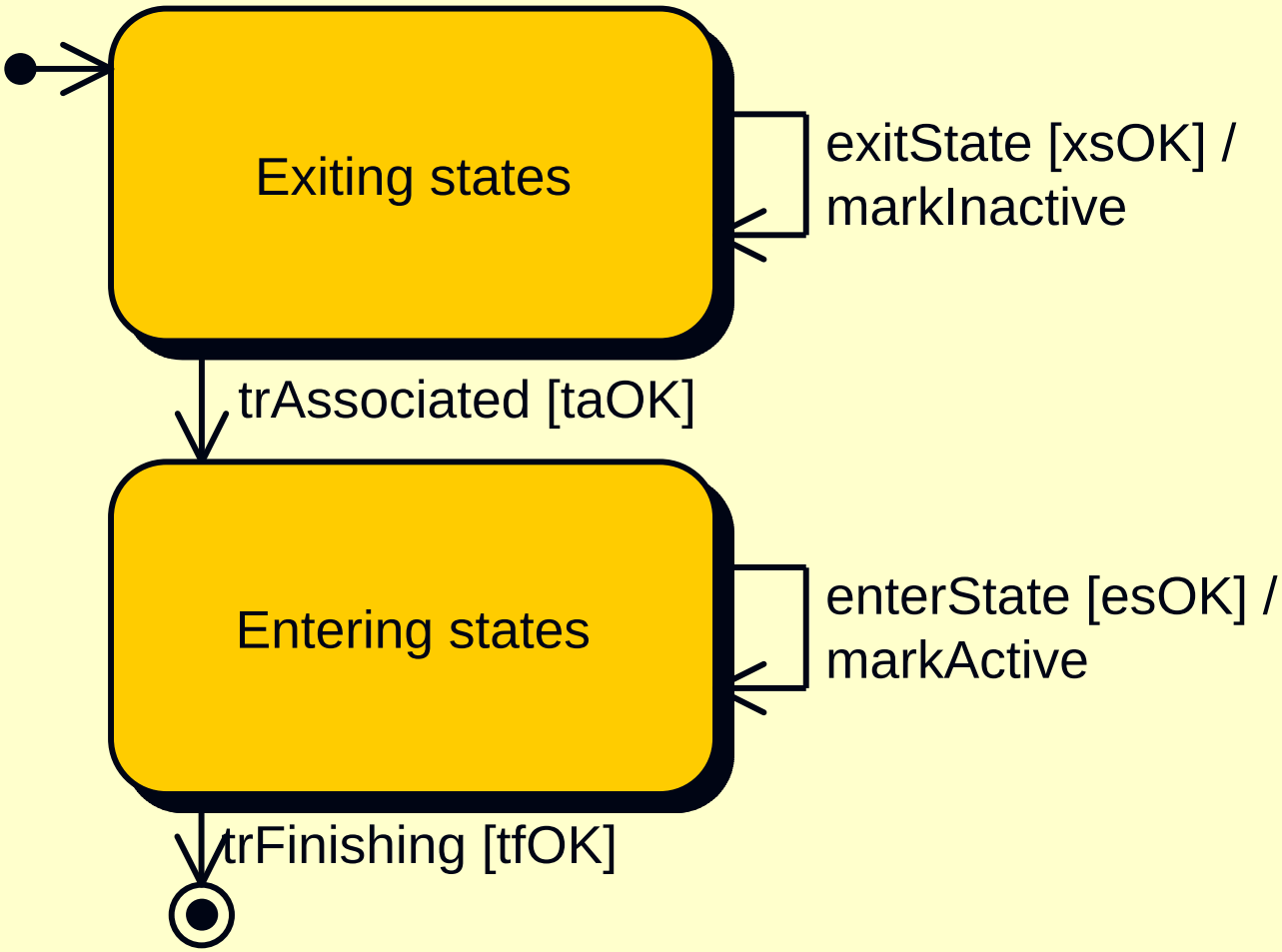
Transition context



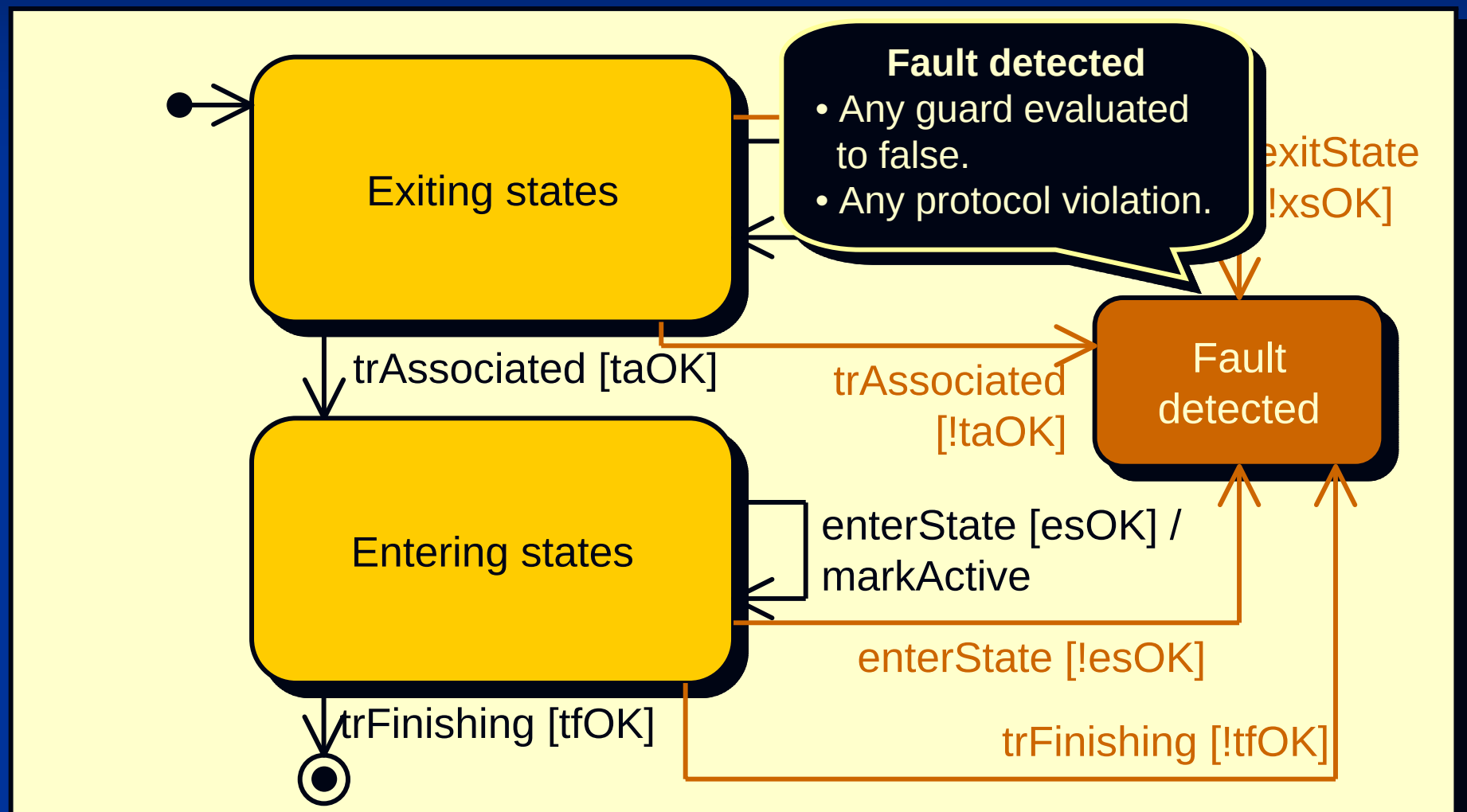
Transition context



Transition context

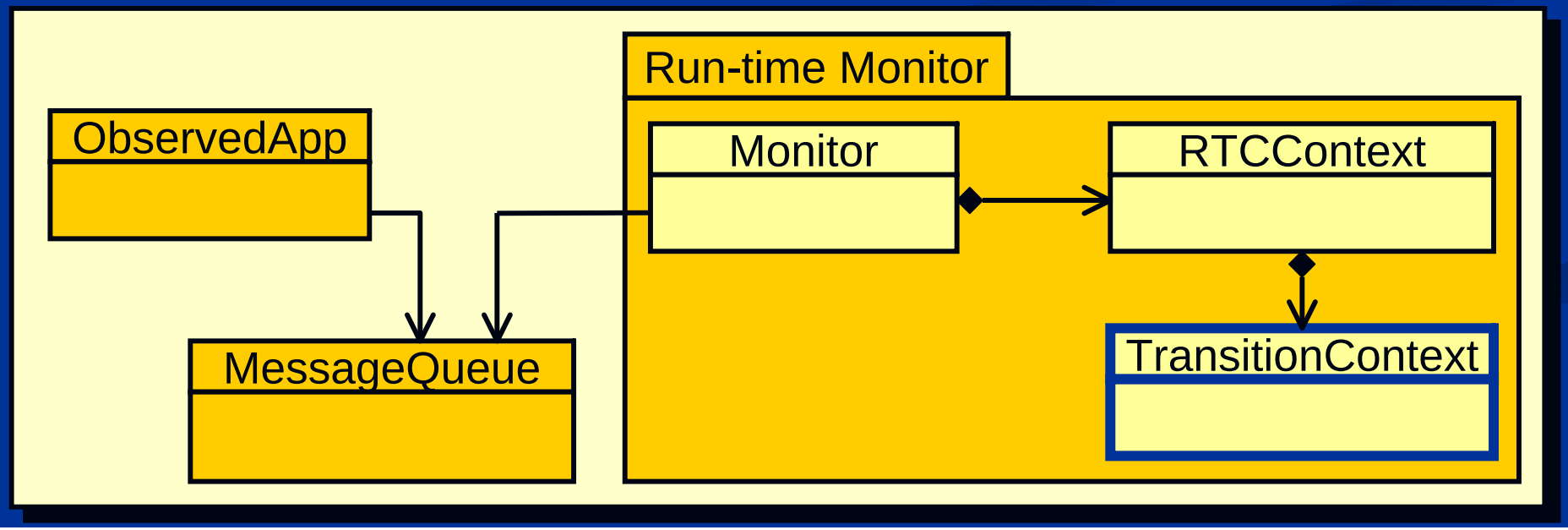


Transition context



Checking the internal behavior

- Structural decomposition:
  - *Run-to-completion* and *transition contexts*
- Specification of contexts:
  - Protocol state machines (statecharts)



Abstract, high-level control-flow fault detection

Reference information:
- Automatically derived from the behavioral specification
- Capable of expressing state hierarchies, concurrent operation, etc.

Implementation of the monitor:
- Based on the operational semantics of the behavioral model
- Run-time checking of the behavior on the basis of the abstract reference model

Implementation of the instrumentation:
- Providing information to the monitor about the internal behavior
- Configurable, transparent and automatically applied

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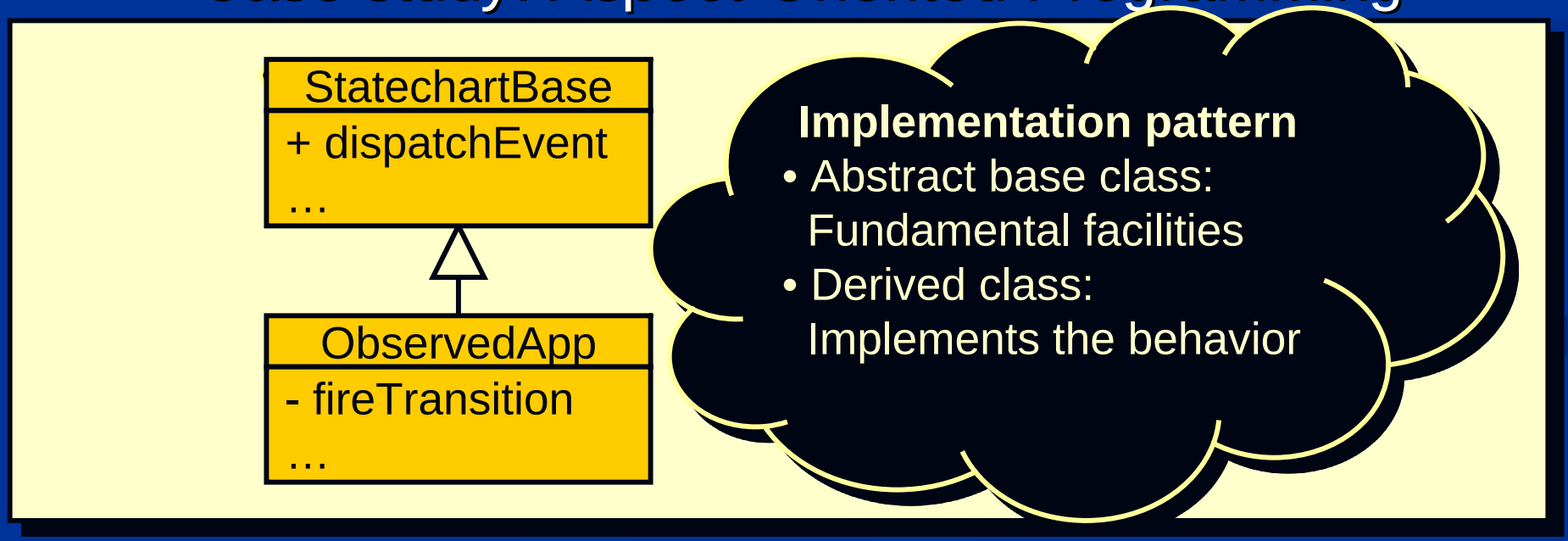
Instrumentation

- Systematic transparent instrumentation:
  - Explicit message transfer to the monitor
  - Modification of the data model and the behavior
  - Case study: Aspect-Oriented Programming



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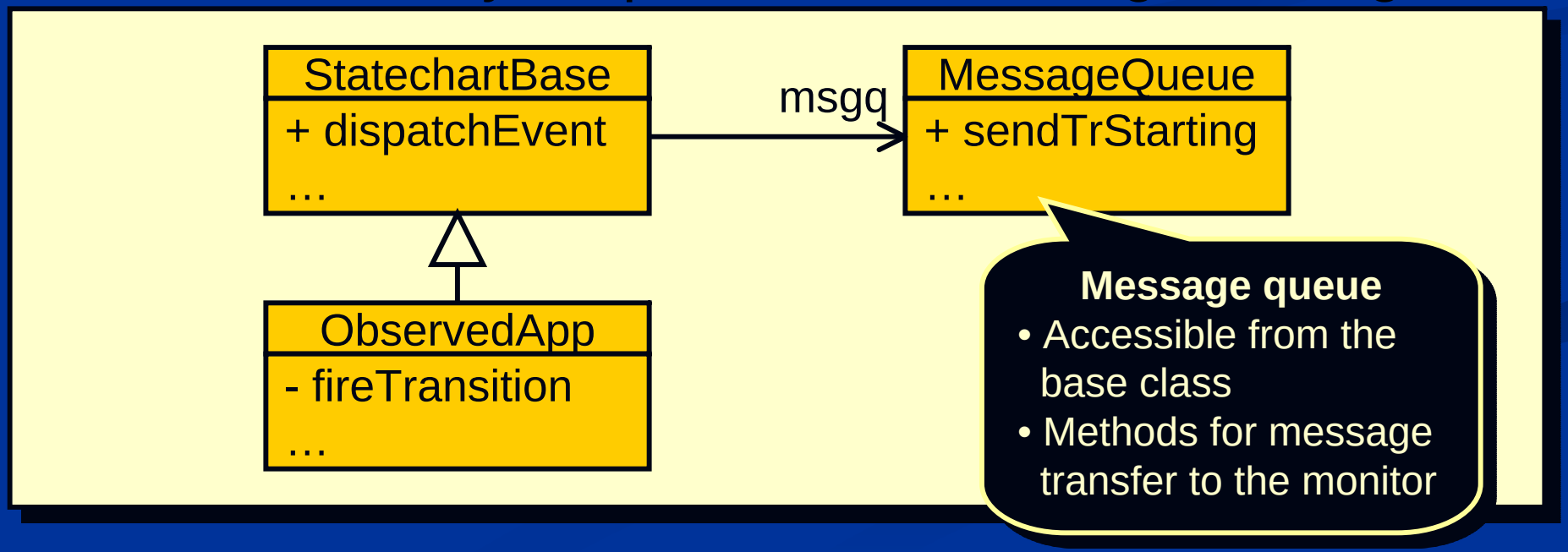
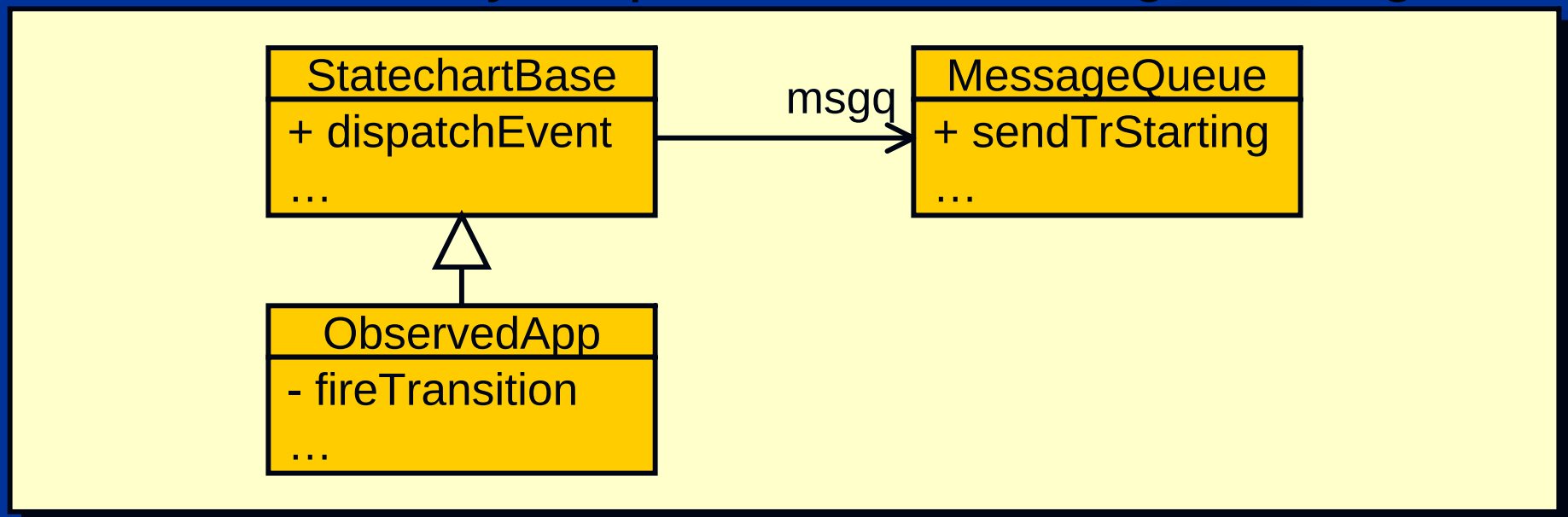


Instrumentation

- Systemat
  - Explicit r
  - Modifica
  - Case study: Aspect Oriented Programming

Adding a member variable (Java AOP)

```
public aspect BehavioralMonitoring {
    // Add a member variable to the base class
    protected MessageQueue StatechartBase.msgq;
    ...
}
```



Instrumentation

- Systematic transparent instrumentation:
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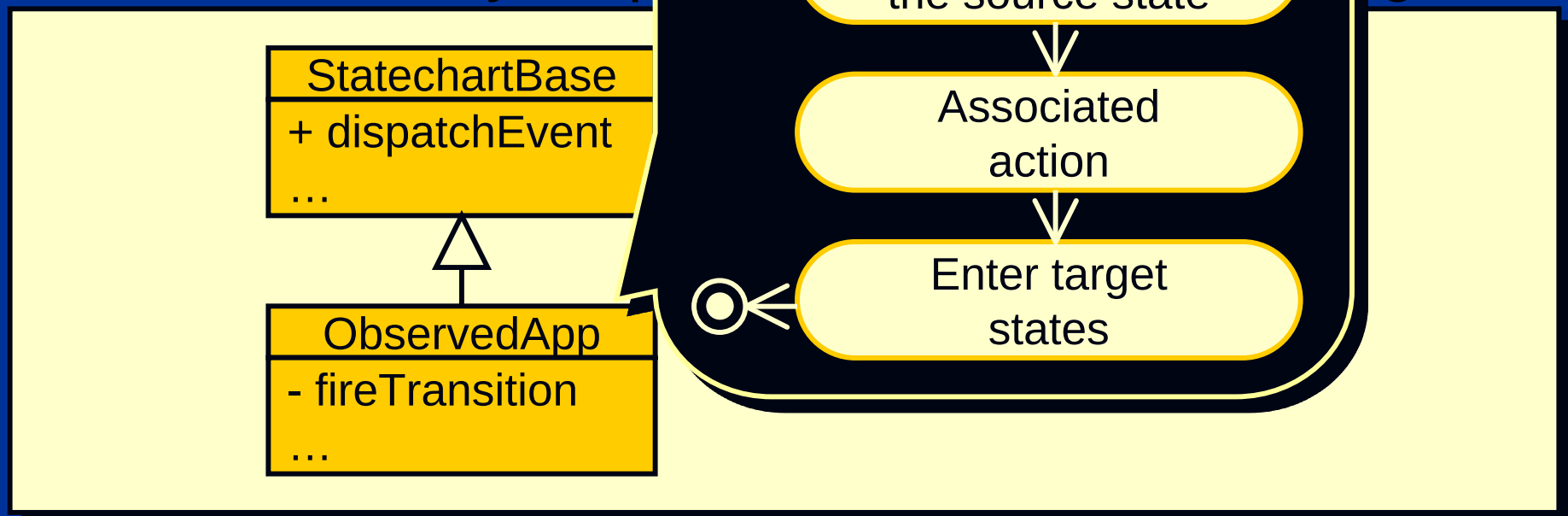
  - Modification of t
  - Case study: Asp



Instru

- Systematic trans n:
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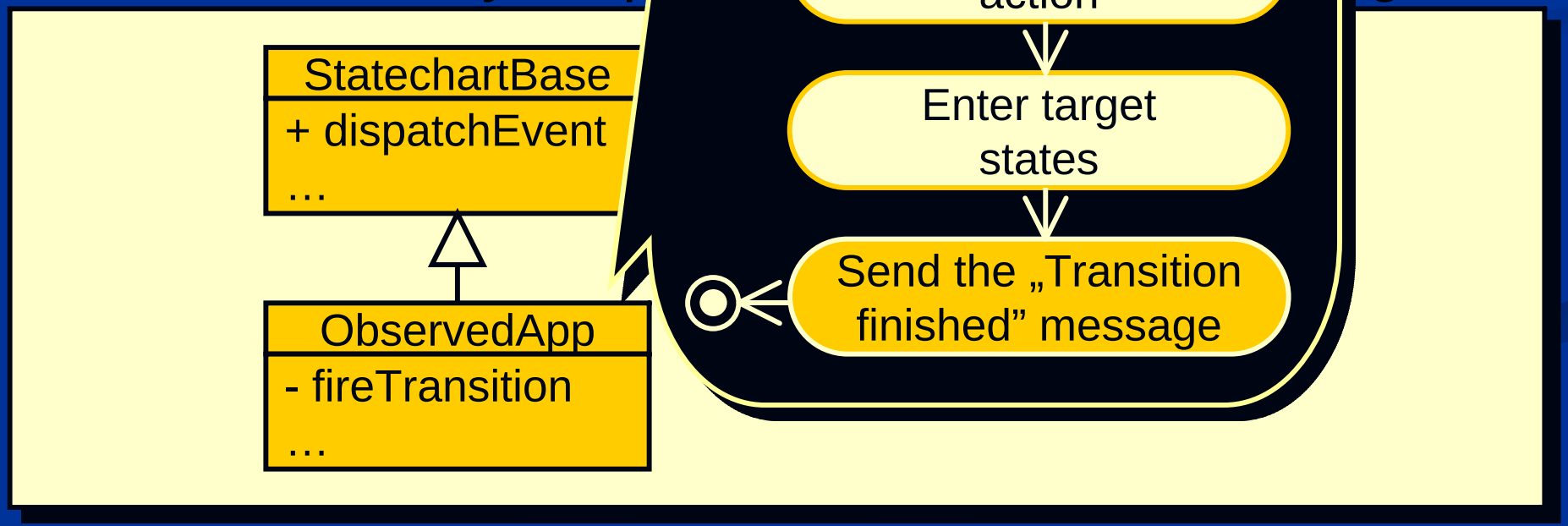

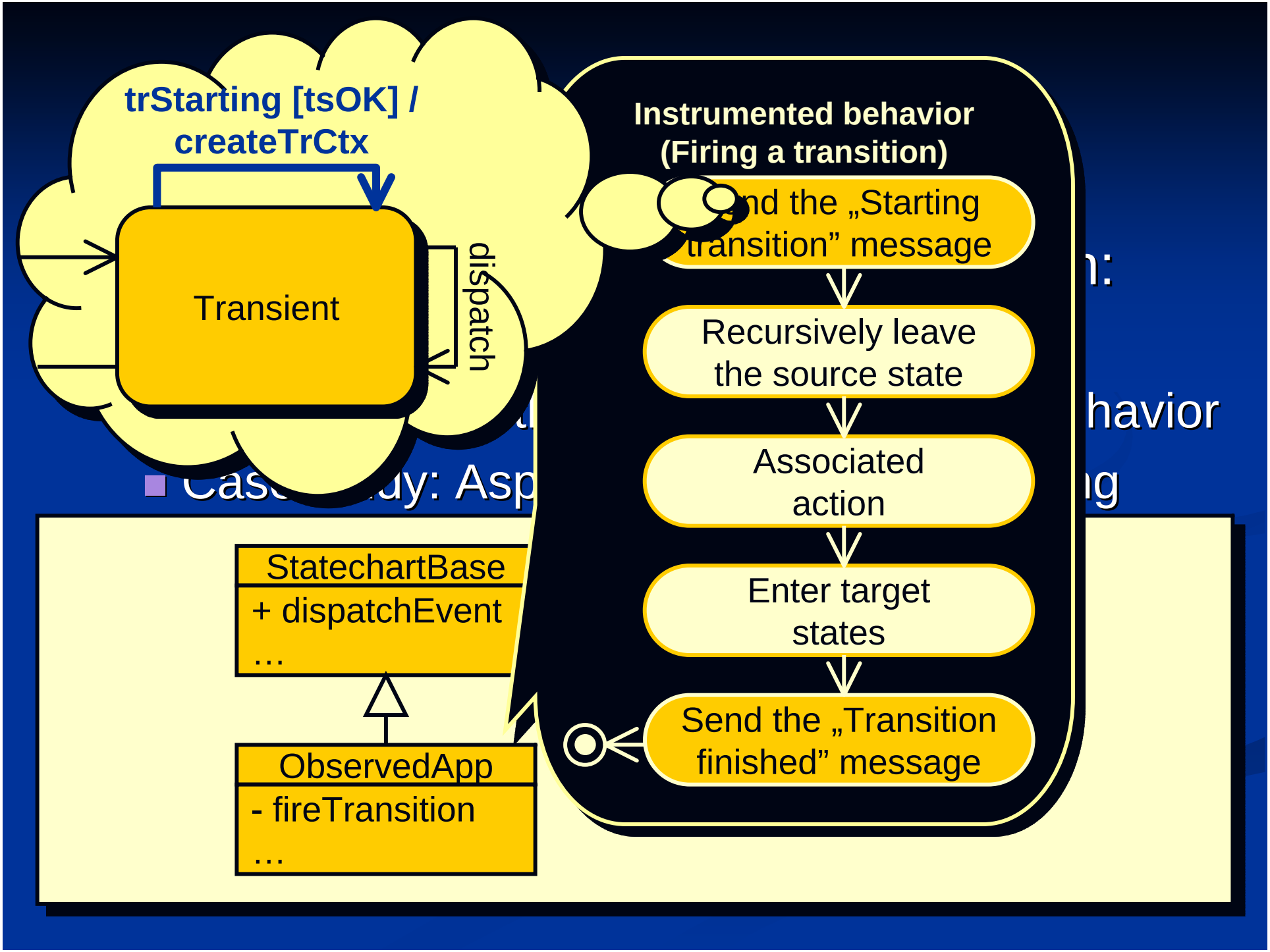
trStarting [tsOK] /
createTrCtx
Transient
dispatch
Instrumented behavior
(Firing a transition)
nd the „Starting
transition” message
Recursively leave
the source state
Associated
action
Enter target
states
Send the „Transition
finished” message
StatechartBase
+ dispatchEvent
…
ObservedApp
- fireTransition
…

Instru

- Systematic trans n:
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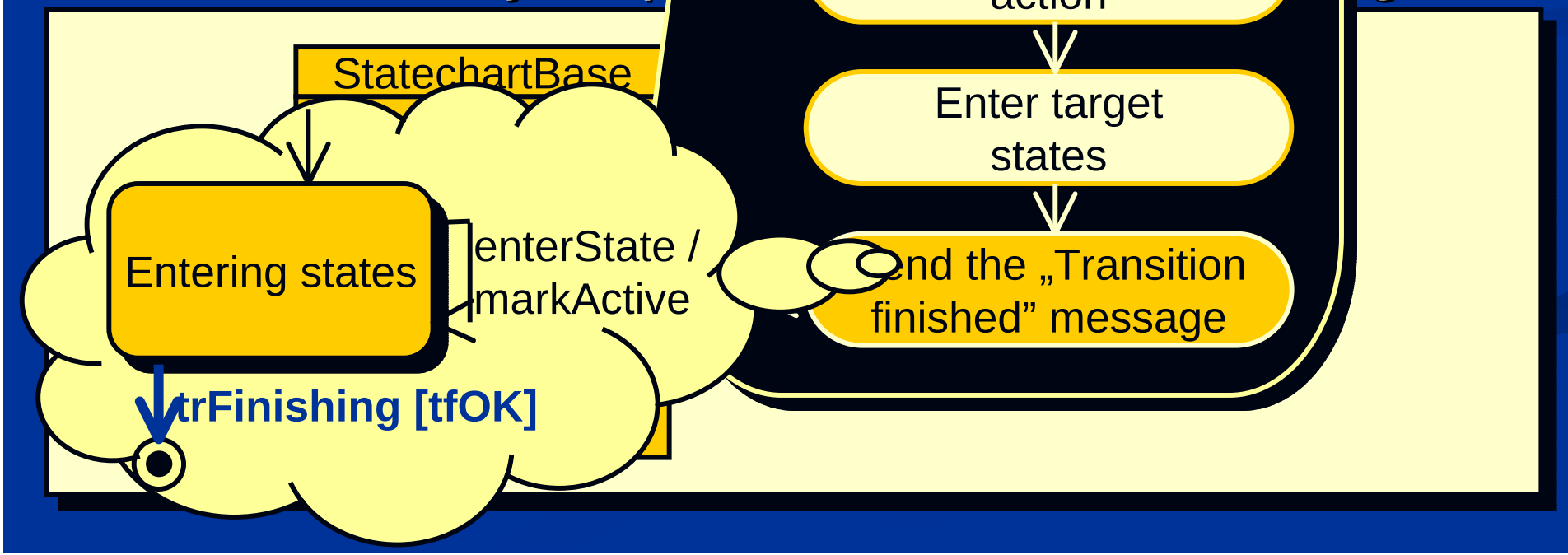


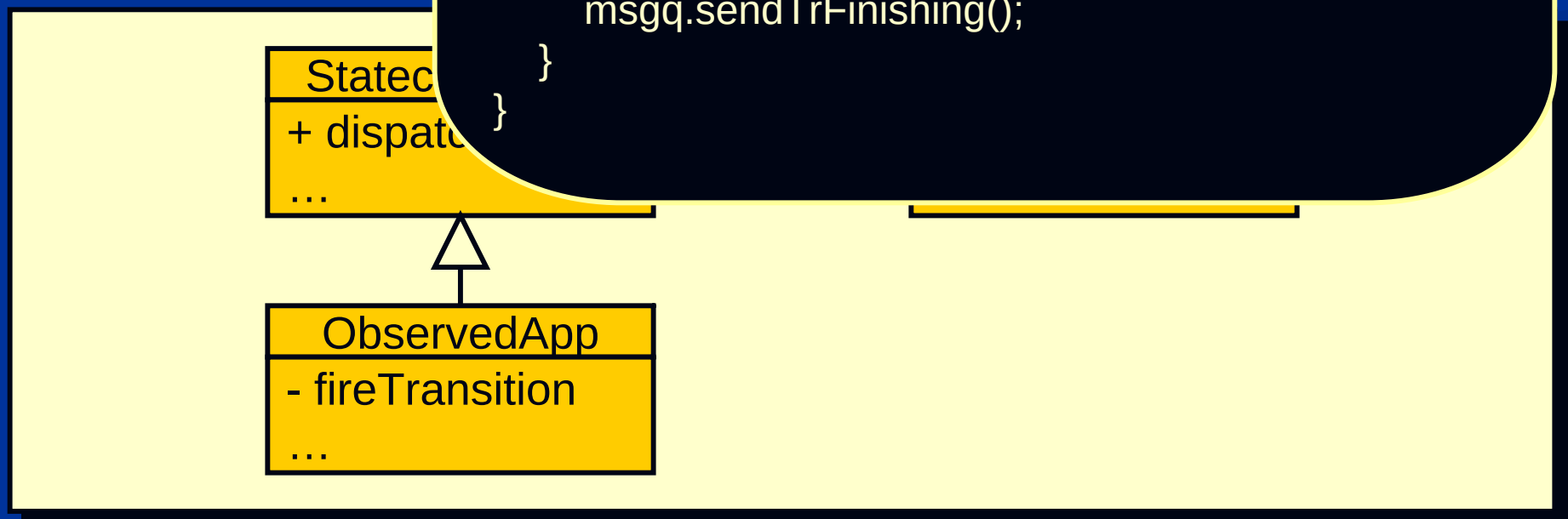
In

- Systemat
  - Explicit r
  - Modifica
  - Case stu

Add code around function call (Java AOP)

```
public aspect BehavioralMonitoring {
    // Define pattern matching calls to fireTransition
    pointcut firingTransitionPattern
        call (StatechartBase+.fireTransition(Transition t));

    // Define instrumentation to be applied
    around(): firingTransitionPattern() {
        msgq.sendTrStarting();
        proceed();
        msgq.sendTrFinishing();
    }
}
```



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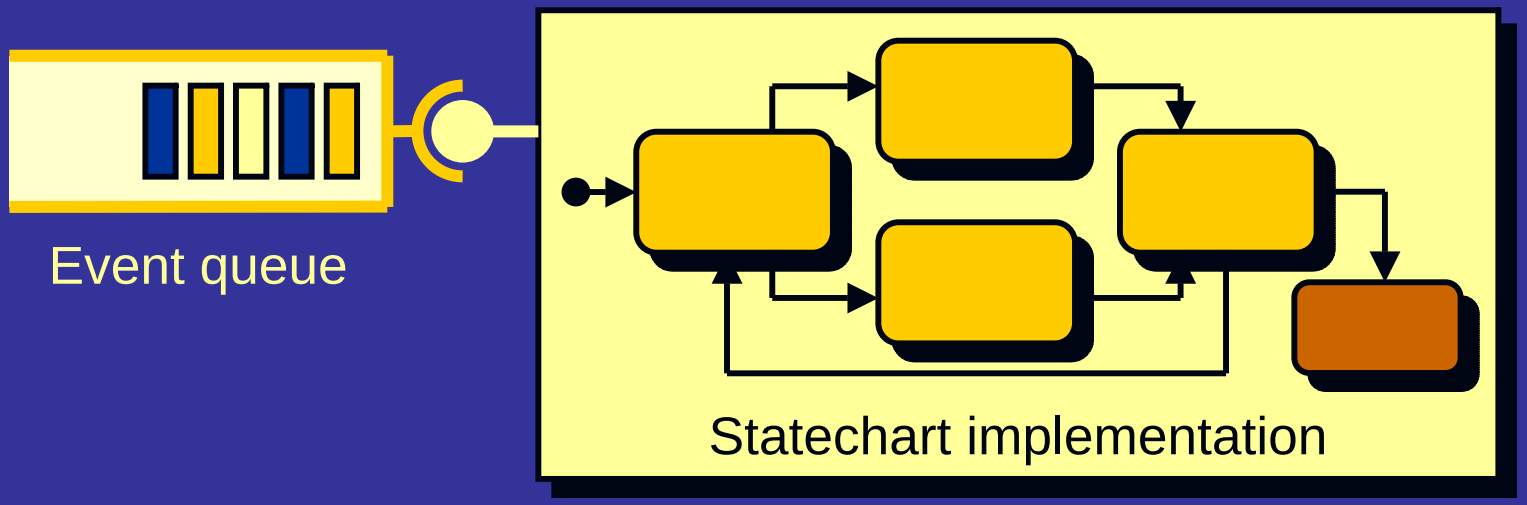
Summary

- Monitoring of the dynamic behavior
  - Verification against abstract specification
  - Pattern-based instrumentation scheme
- Prototype implementation
  - Benchmark experiment: bit-inversion faults in the statechart implementation (C++ version)
    - HW: 40%, monitor: 21.5%, SW: 18.5%
  - Instrumentation case study (Java, AspectJ):
    - Run-time overhead: 10.9%

Future work



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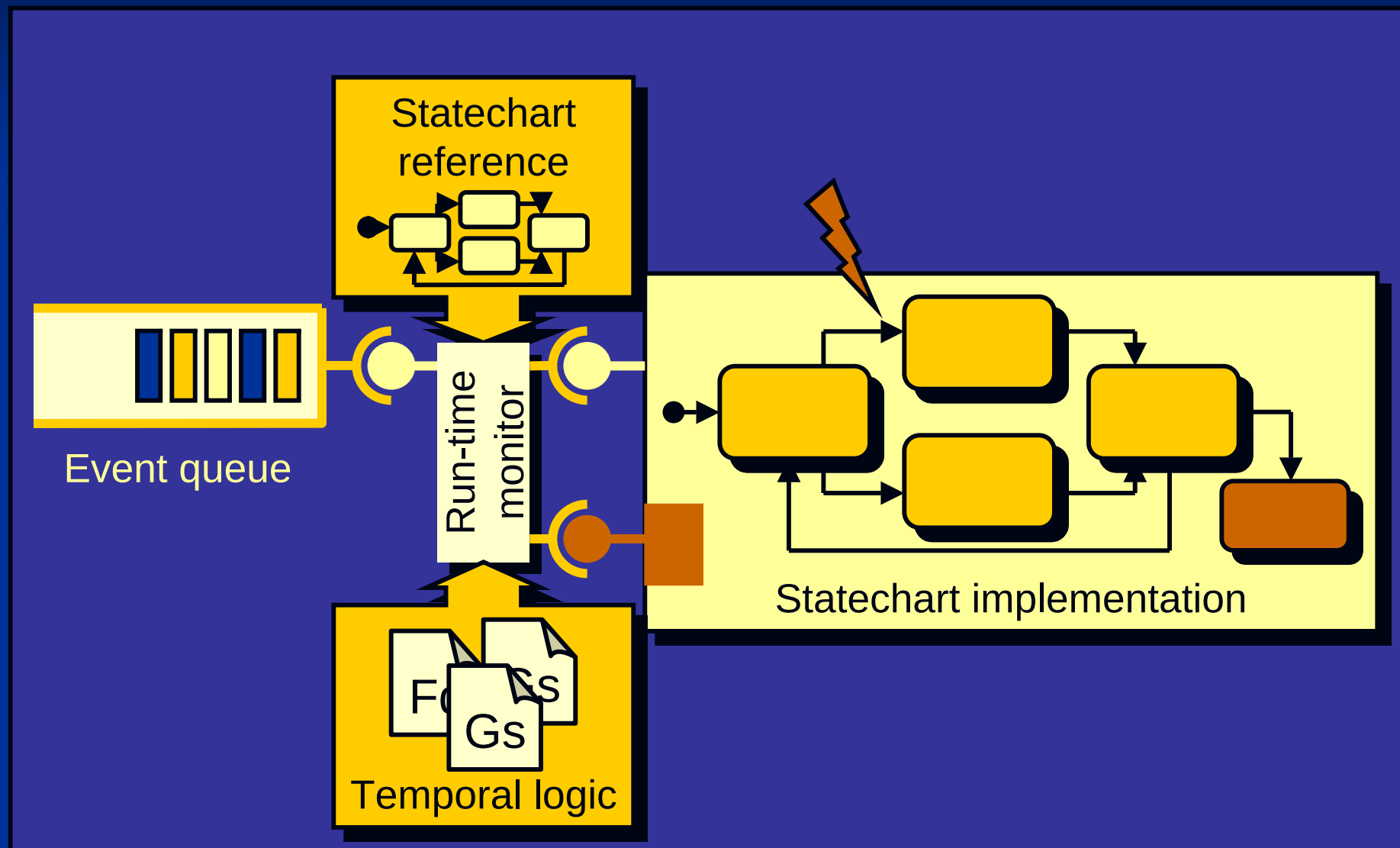
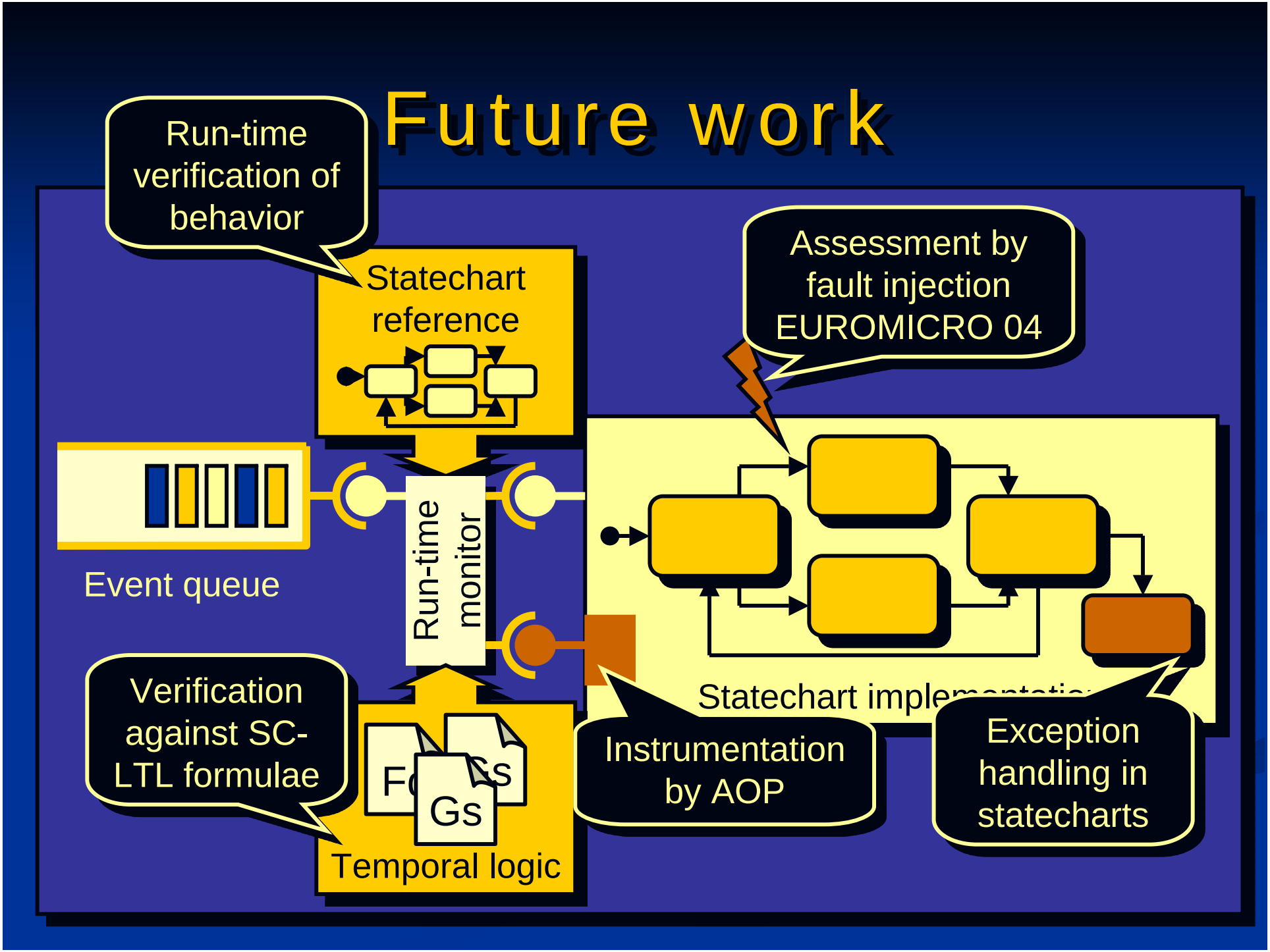

Statechart reference
Event queue
Run-time monitor
Statechart implementation
Gs
Temporal logic

Future work


Run-time verification of behavior
Statechart reference
Assessment by fault injection EUROMICRO 04
Event queue
Run-time monitor
Verification against SC-LTL formulae
Gs
Temporal logic
Instrumentation by AOP
Exception handling in statecharts

Futu

Run-time fault detection of statechart implementations

- Formal reference
- Temporal logic fitted to statecharts
- Exception handling
- No manual modification on the implementation (AOP)
- Original event dispatcher interface