Synchronous Languages—Lecture 11

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Real-Time Systems and Embedded Systems Group

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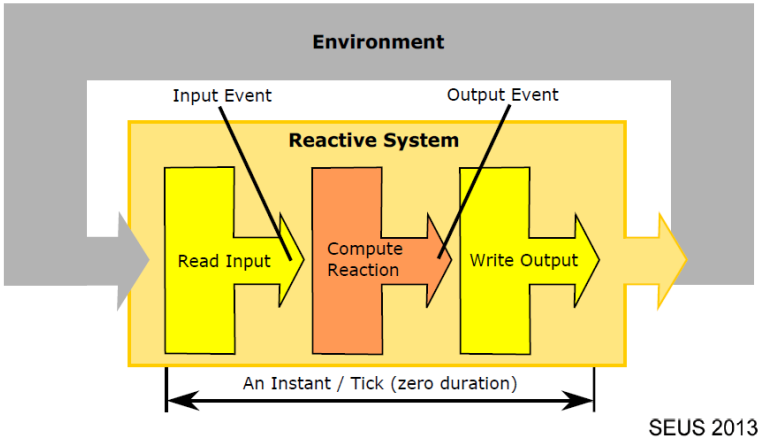
SCCharts — Sequentially Constructive Statecharts for Safety-Critical Applications

Reactive Embedded Systems



- Embedded systems react to inputs with computed outputs

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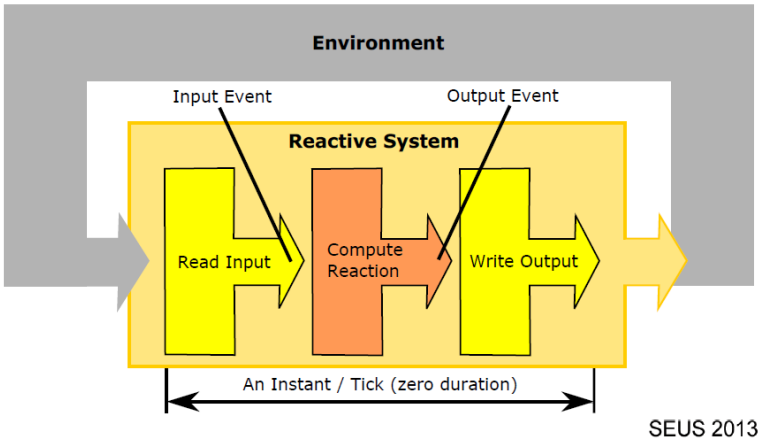

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- Typically state based computations

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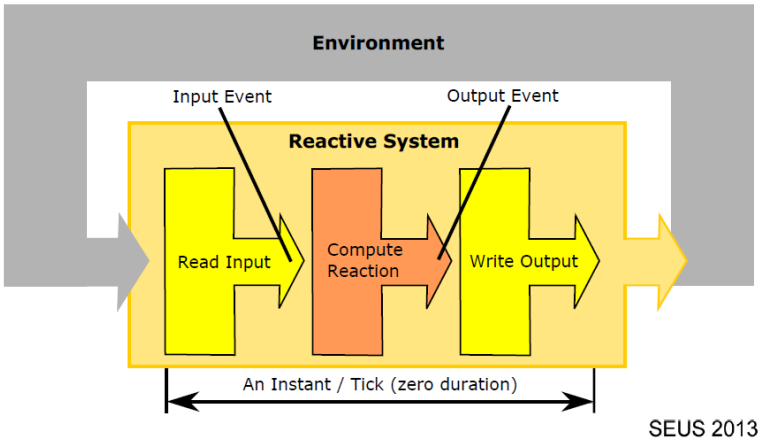

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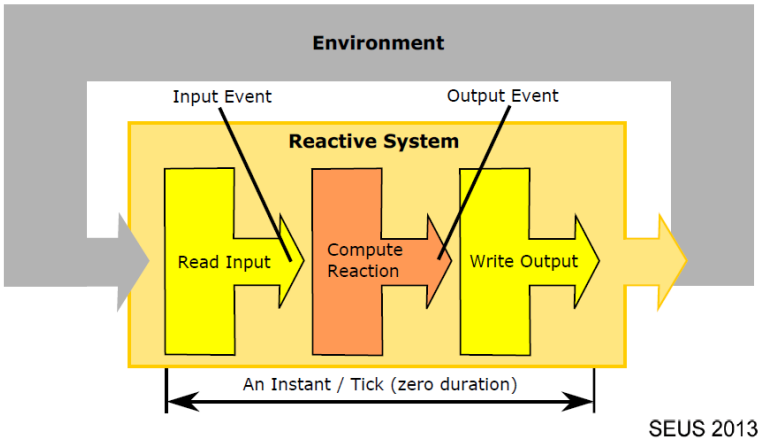

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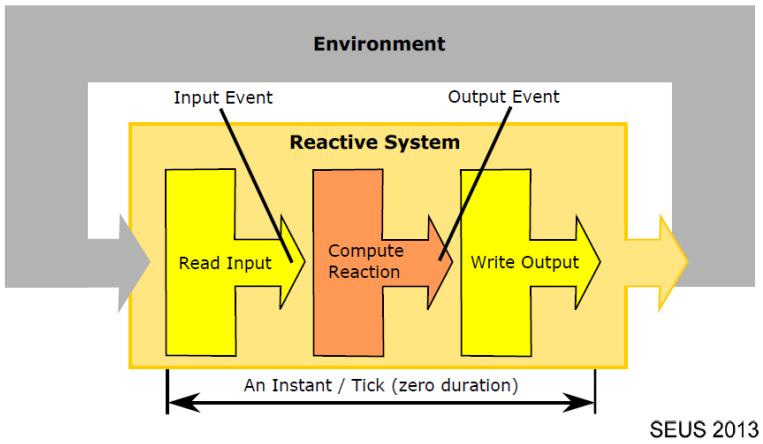

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public class ValueHolder {
   private List listeners = new LinkedList();
   private int value;
   public interface Listener {
      public void valueChanged(int newValue);
   }
   public void addListener(Listener listener) {
      listeners.add(listener);
   }
   public void setValue(int newValue) {
      value = newValue;
      Iterator i = listeners.iterator();
      while(i.hasNext()) {
         ((Listener)i.next()).valueChanged(newValue);
      }
   }
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E. A. Lee, The Problem with Threads, 2006

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- Threads are problematic

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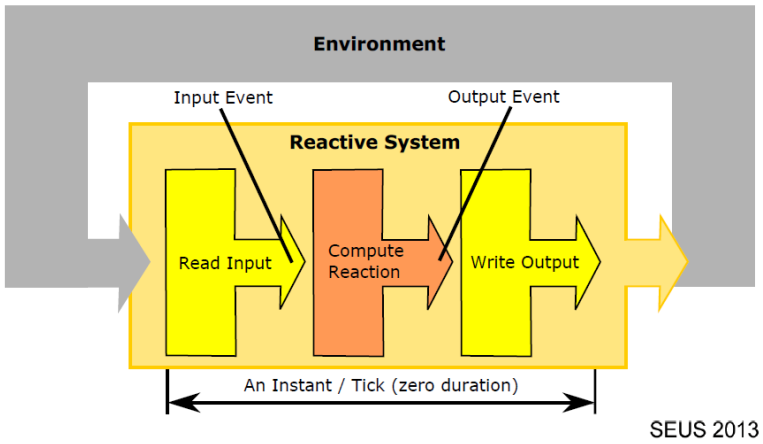

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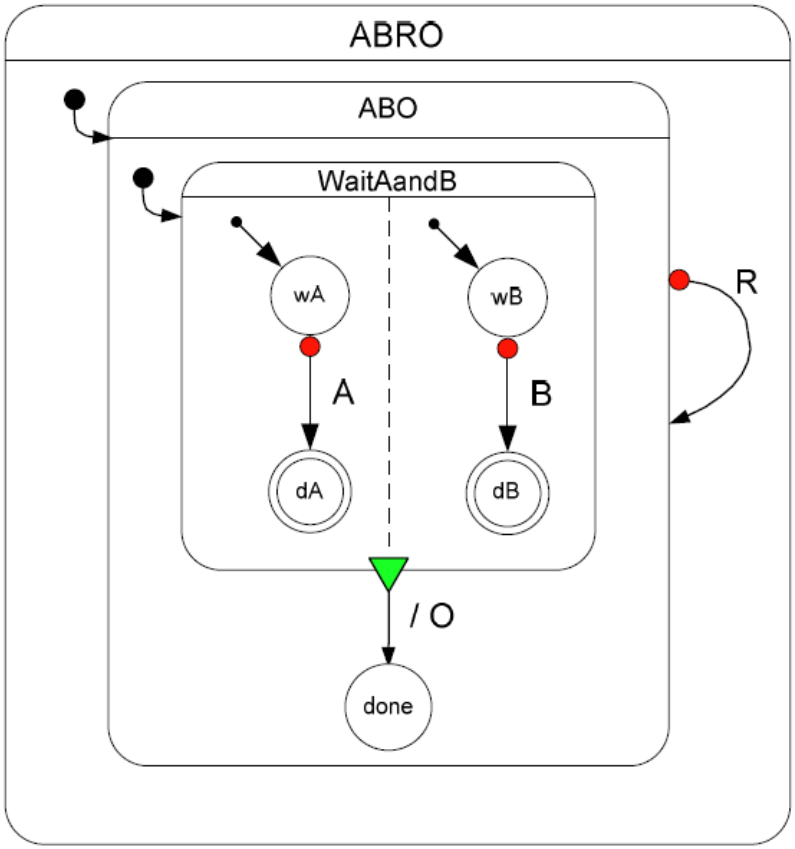
- Embedded systems react to inputs with computed outputs
- Typically state based computations
- Computations often exploit concurrency → Threads
- Threads are problematic → **Synchronous languages**: Lustre, Esterel, SCADE, SyncCharts

SyncCharts

- Statechart dialect for specifying deterministic & robust concurrency

SyncCharts



[Charles André, Semantics of SyncCharts, 2003]

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- SyncCharts:
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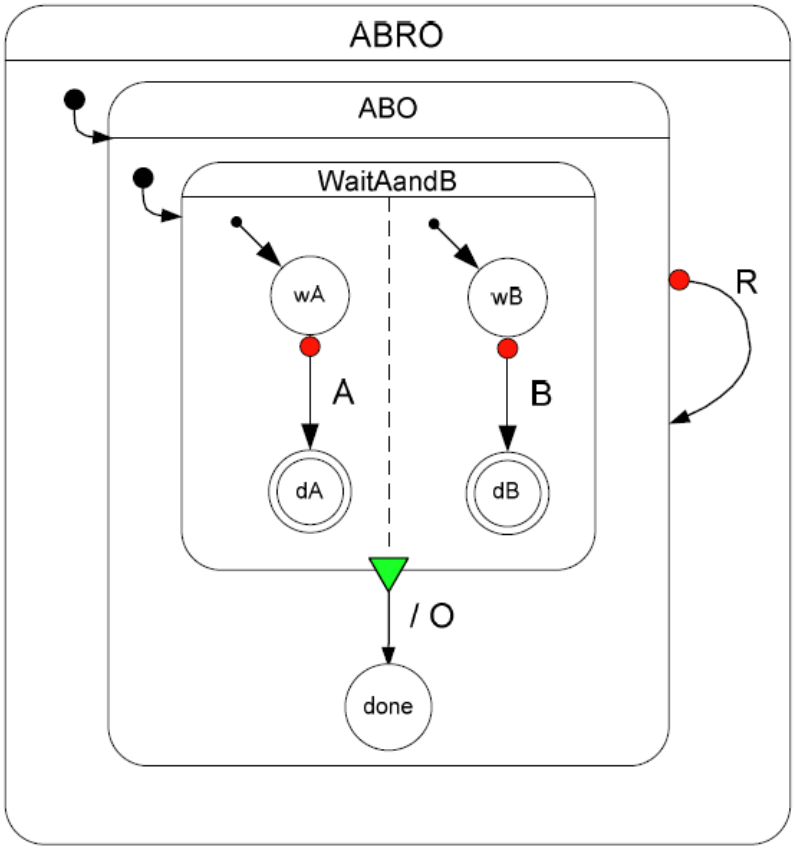

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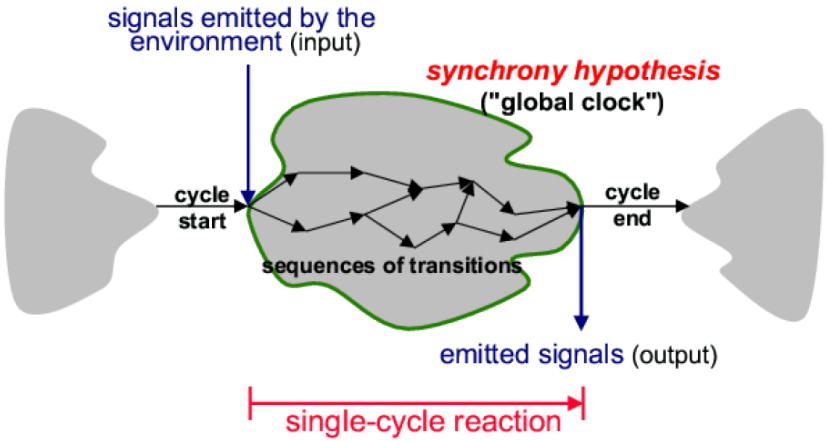
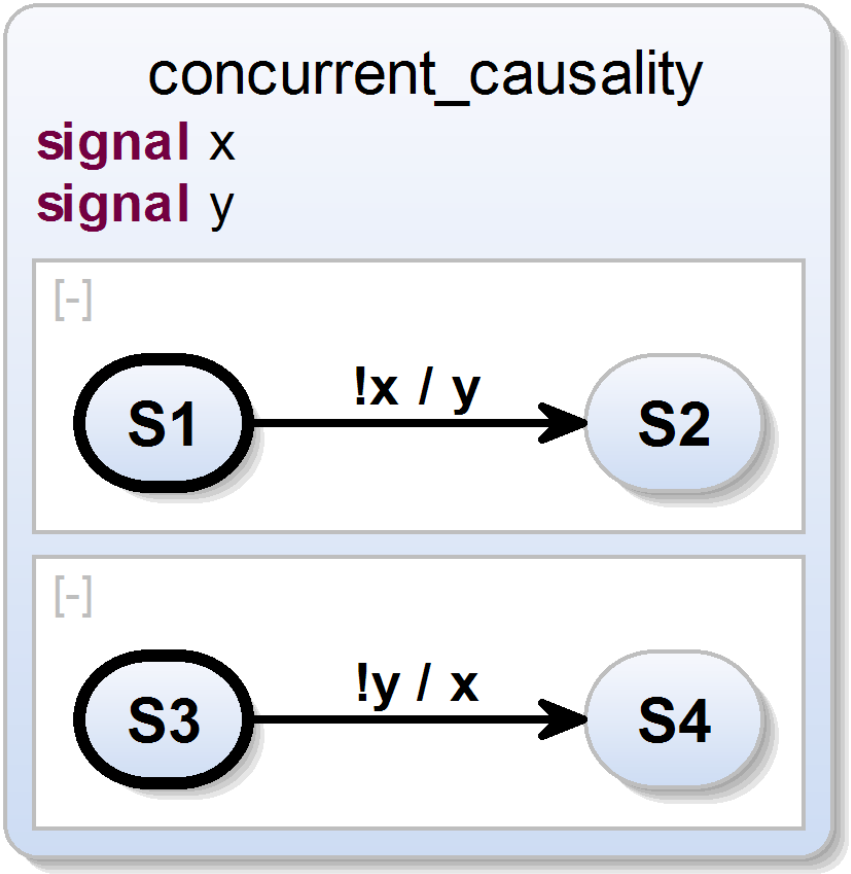
- Statechart dialect for specifying deterministic & robust concurrency
- SyncCharts:
  - Hierarchy, Concurrency, Broadcast
  - Synchrony Hypothesis
    1. Discrete ticks
    2. Computations: Zero time



[Gerald Lüttgen, 2001]

Causality in SyncCharts



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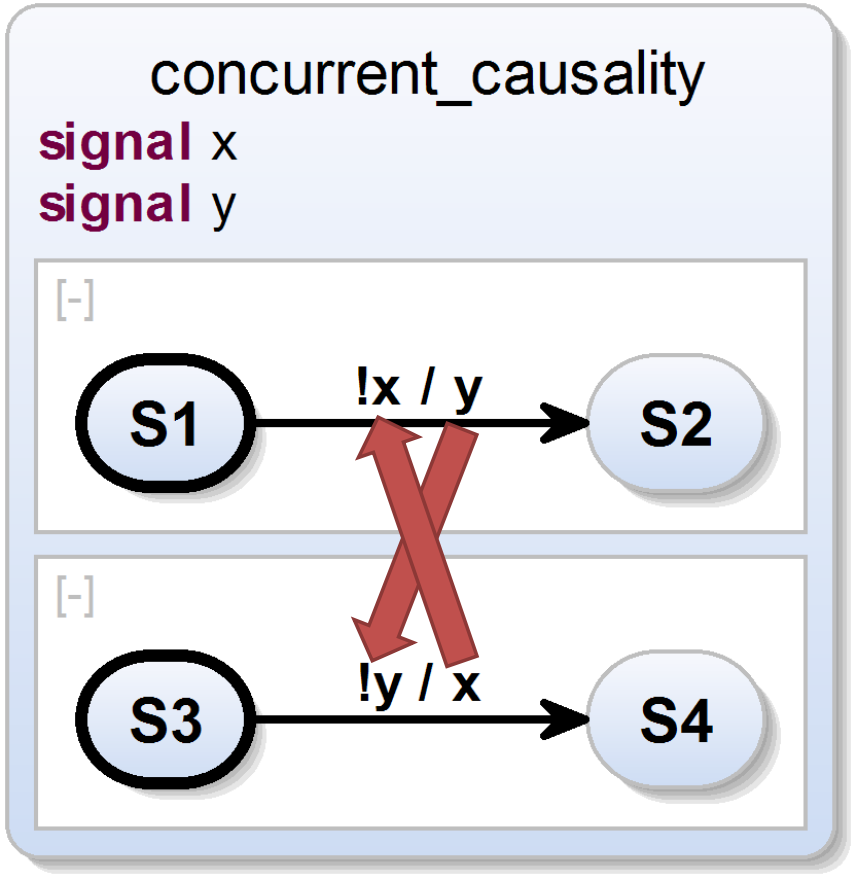

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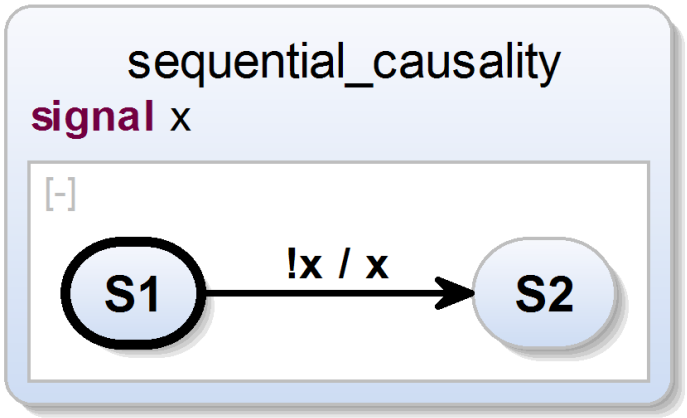

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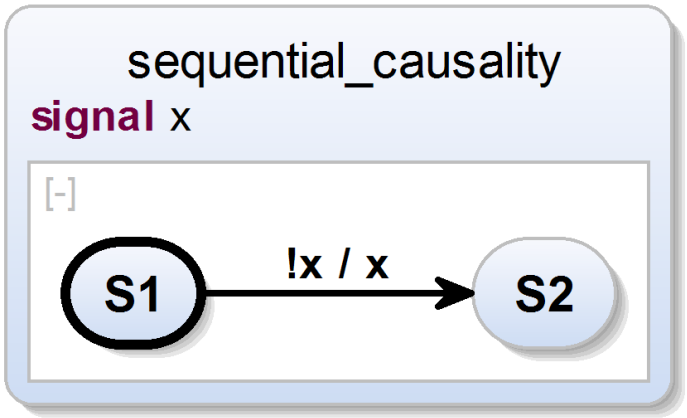


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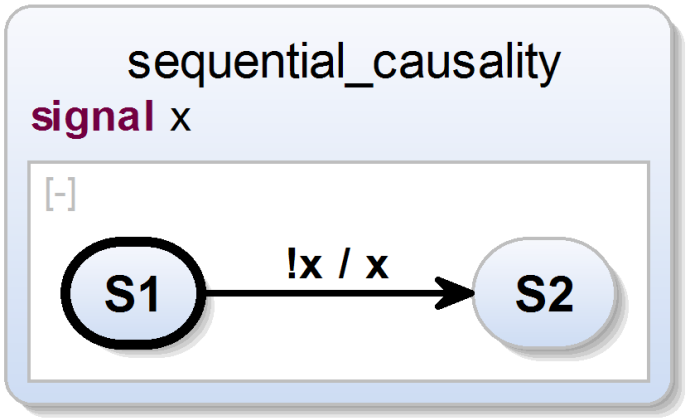


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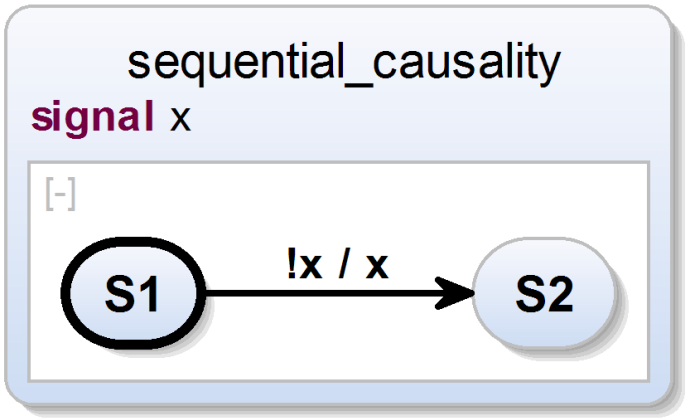


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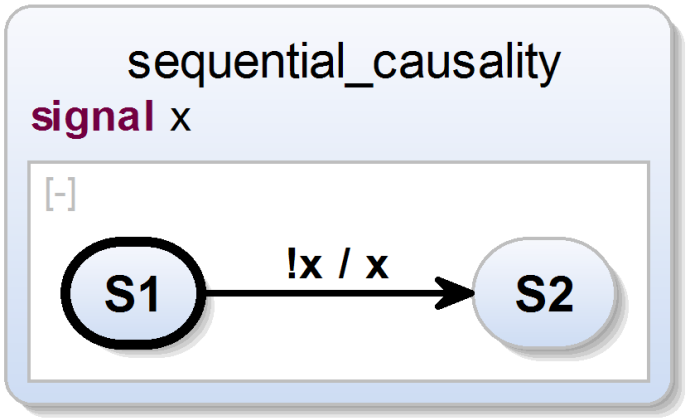


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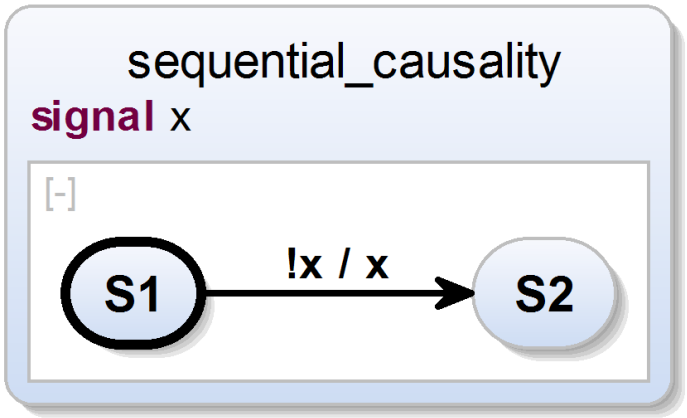


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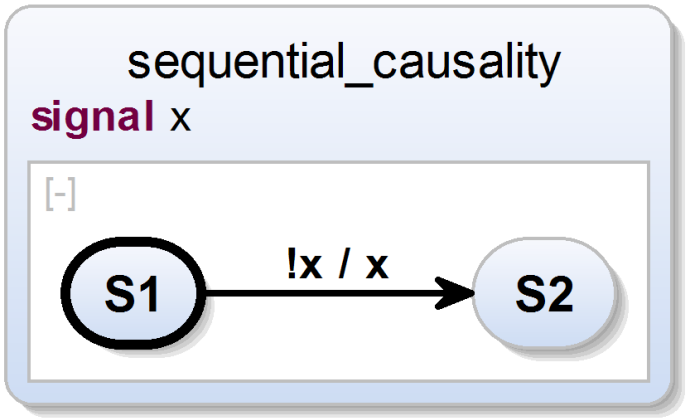


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- Deterministic sequential execution possible

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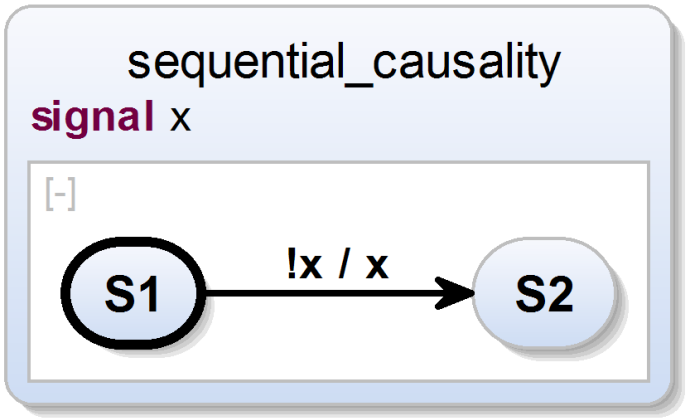


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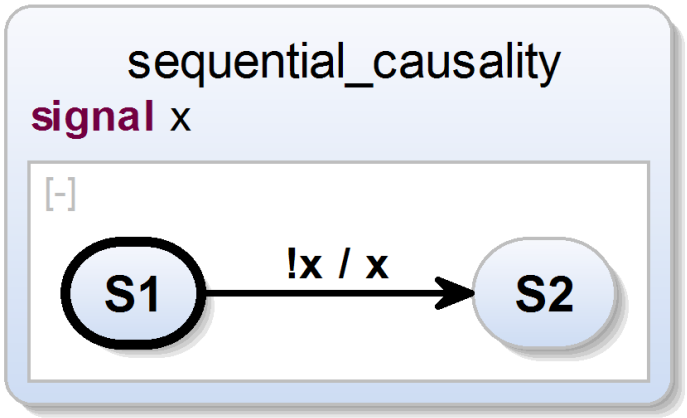


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- Deterministic sequential execution possible using *Sequentially Constructive MoC*
  → **Sequentially Constructive Charts (SCCharts)**

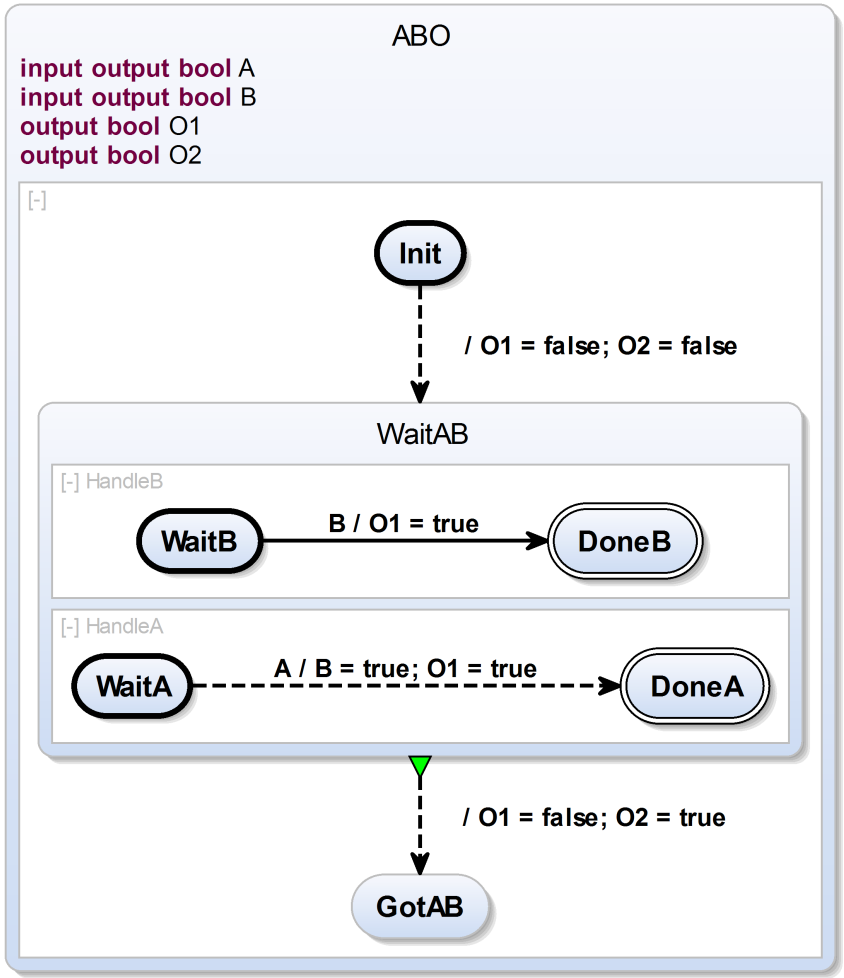
Overview

- SCCharts Overview
- Extended SCCharts → Core SCCharts
- Normalizing Core SCCharts
- Implementation in KIELER

SCCharts Overview

- SCCharts $\widehat{=}$
  SyncCharts syntax +
  Seqentially Constructive semantics

SCCharts Overview



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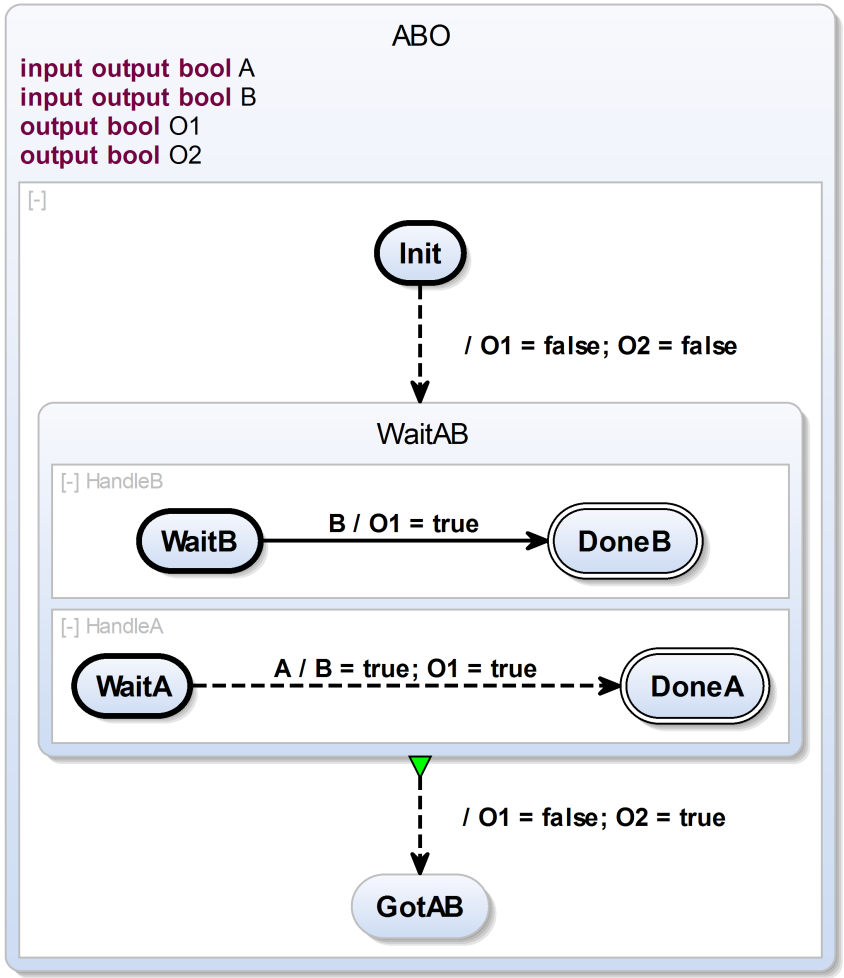

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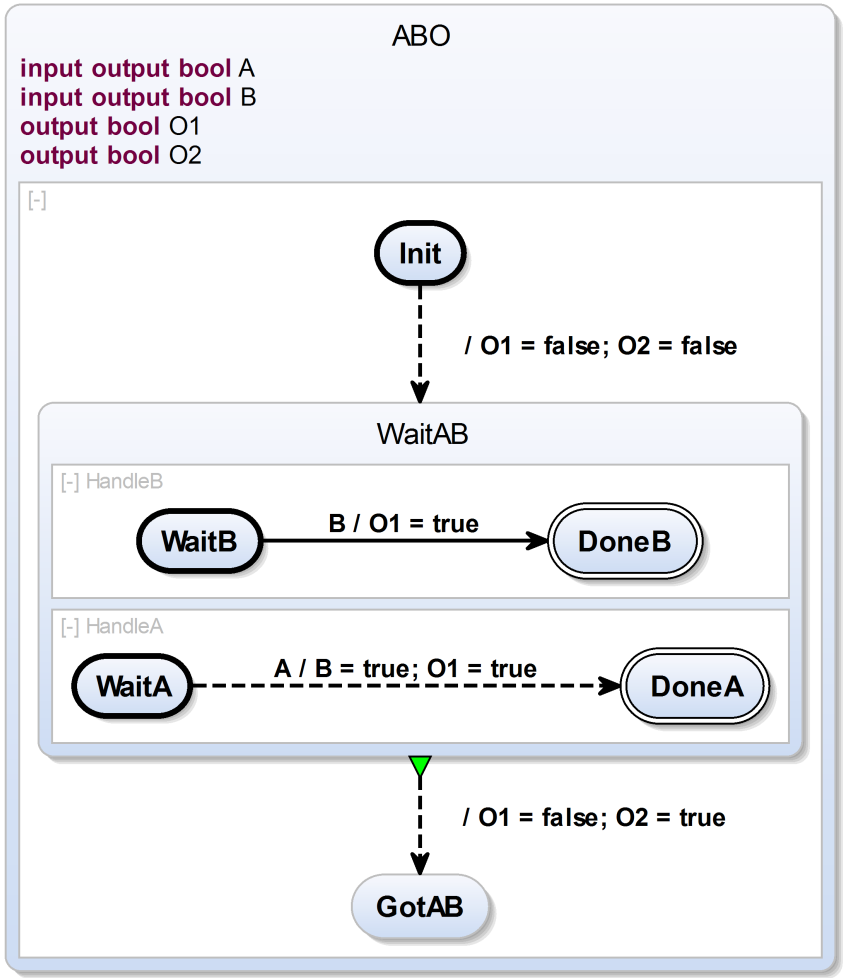

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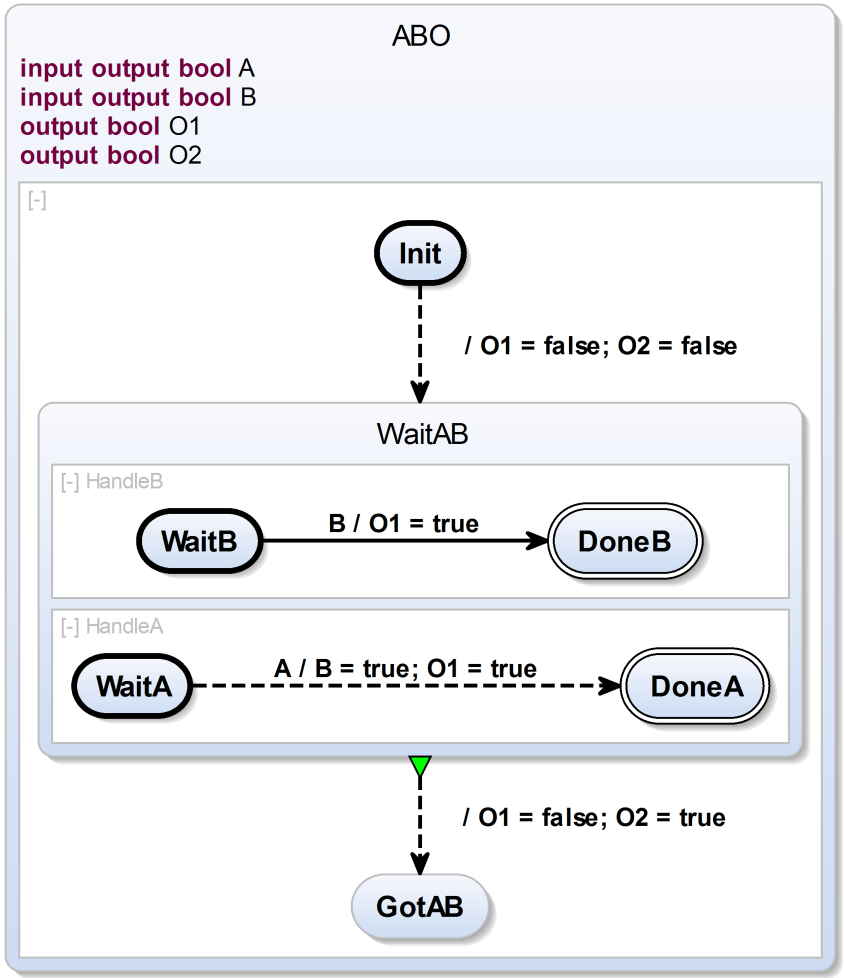

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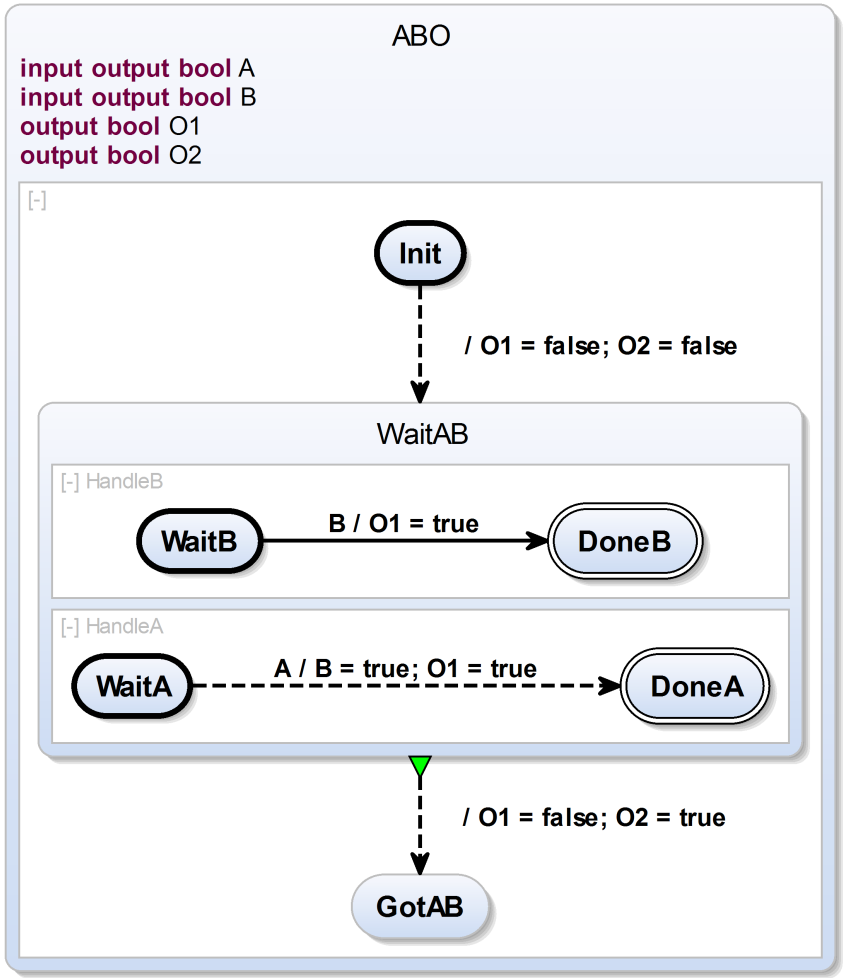

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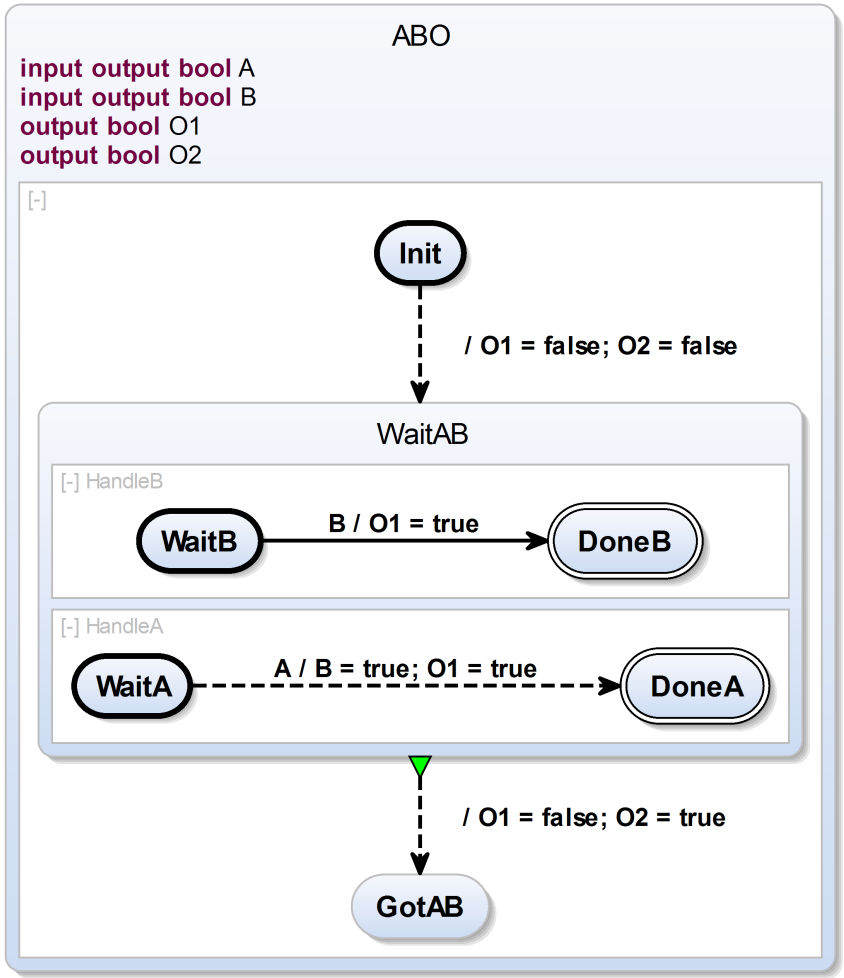

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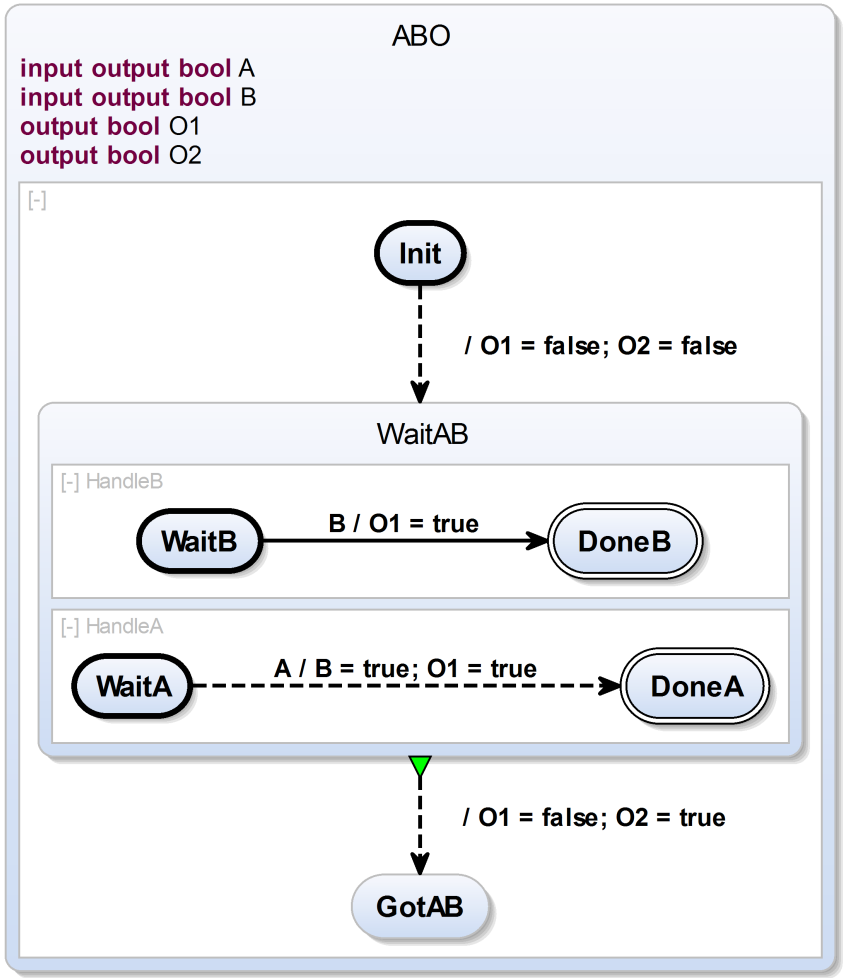

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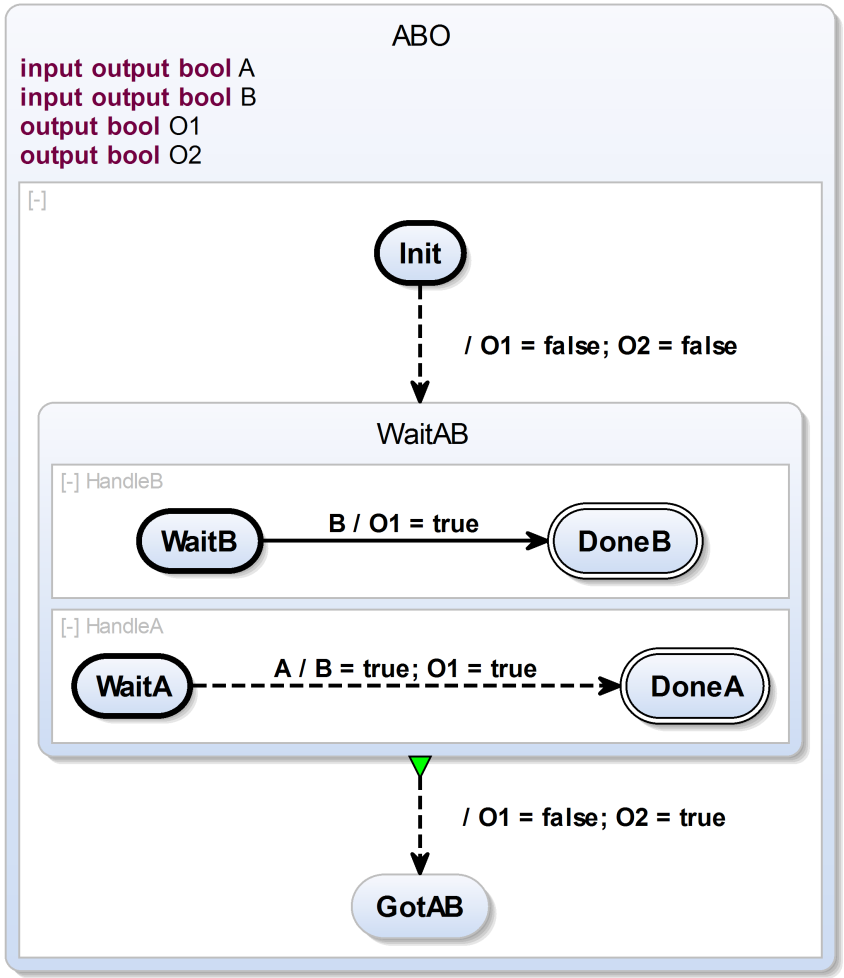

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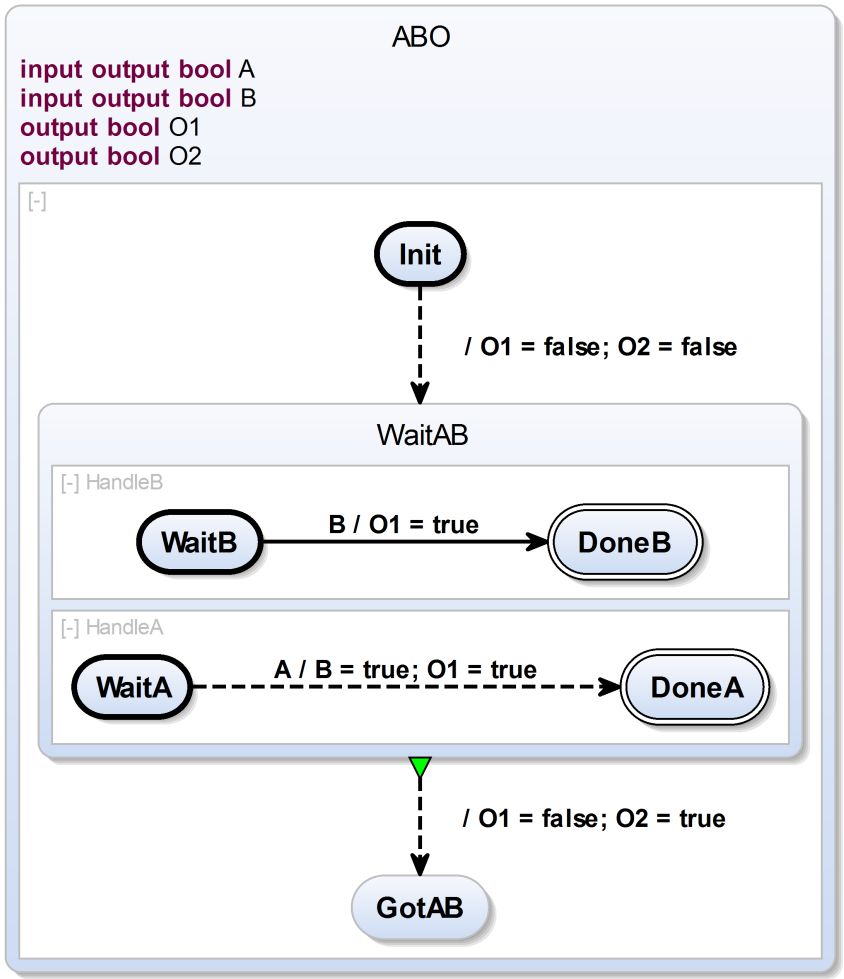

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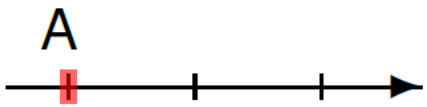

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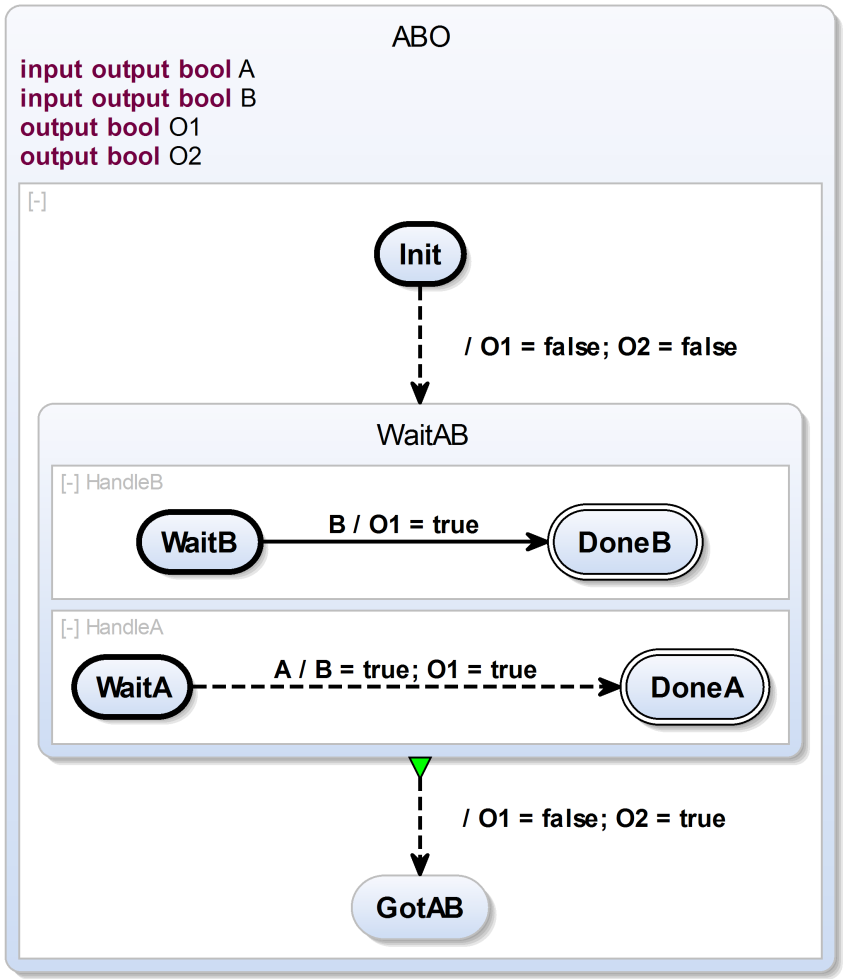

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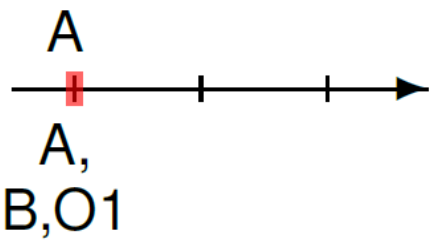

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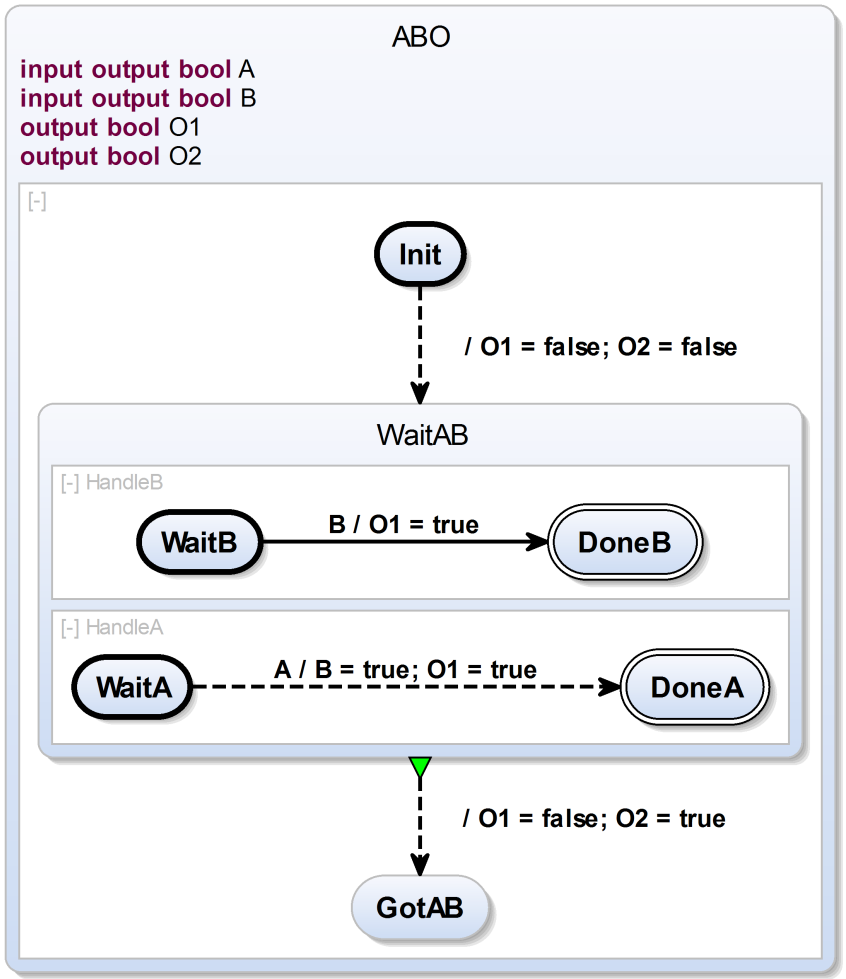

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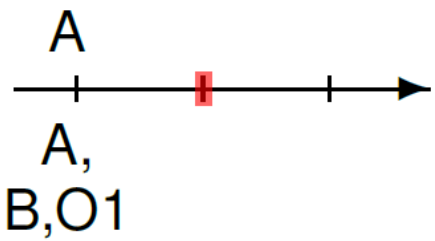

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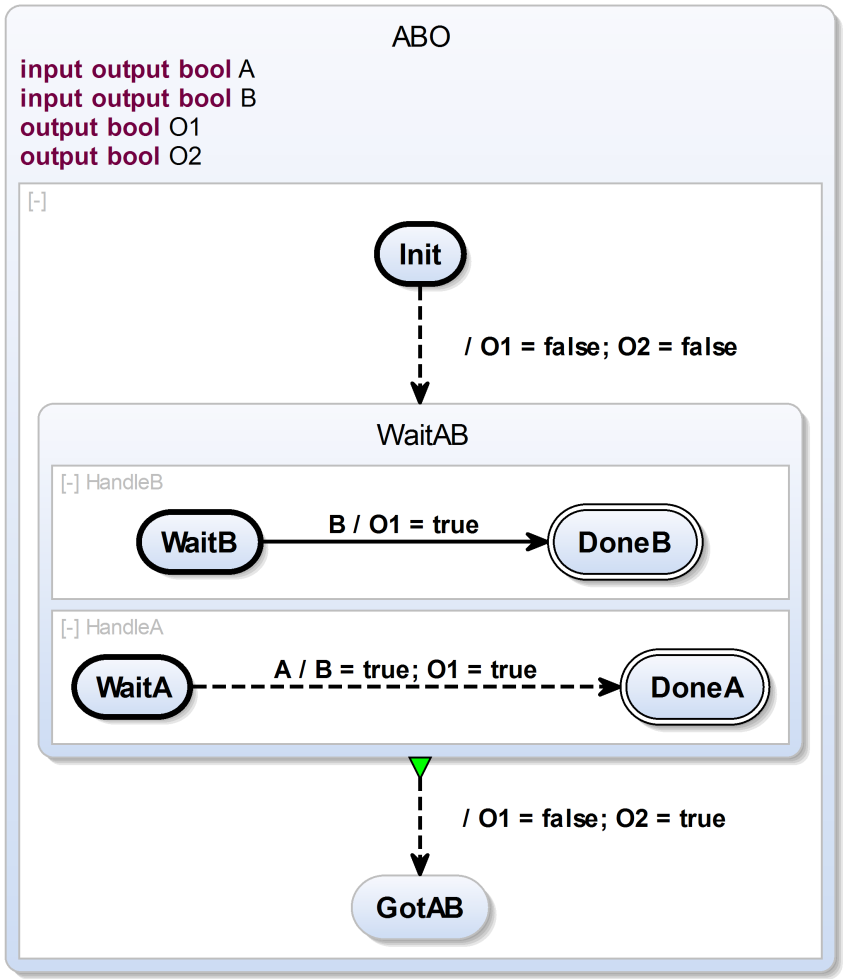

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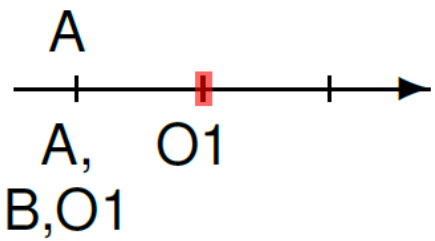

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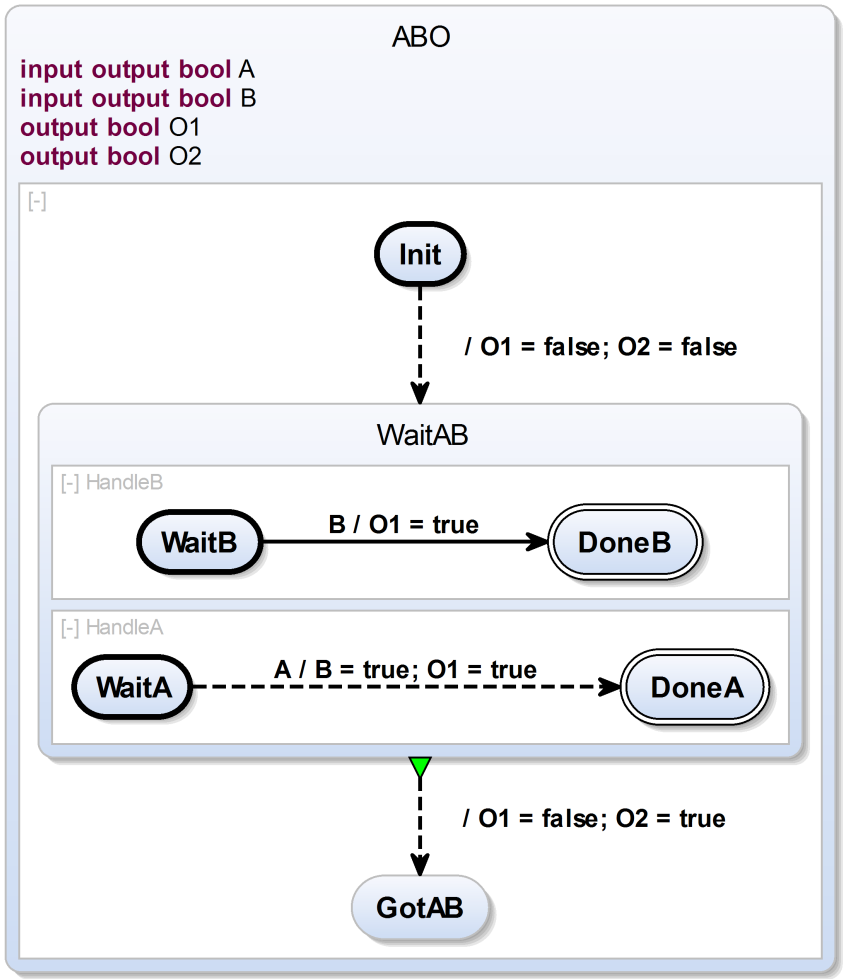

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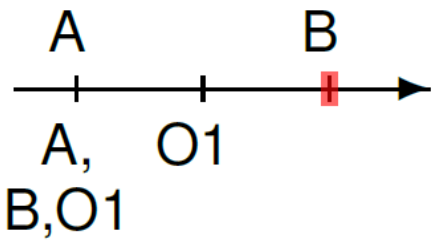

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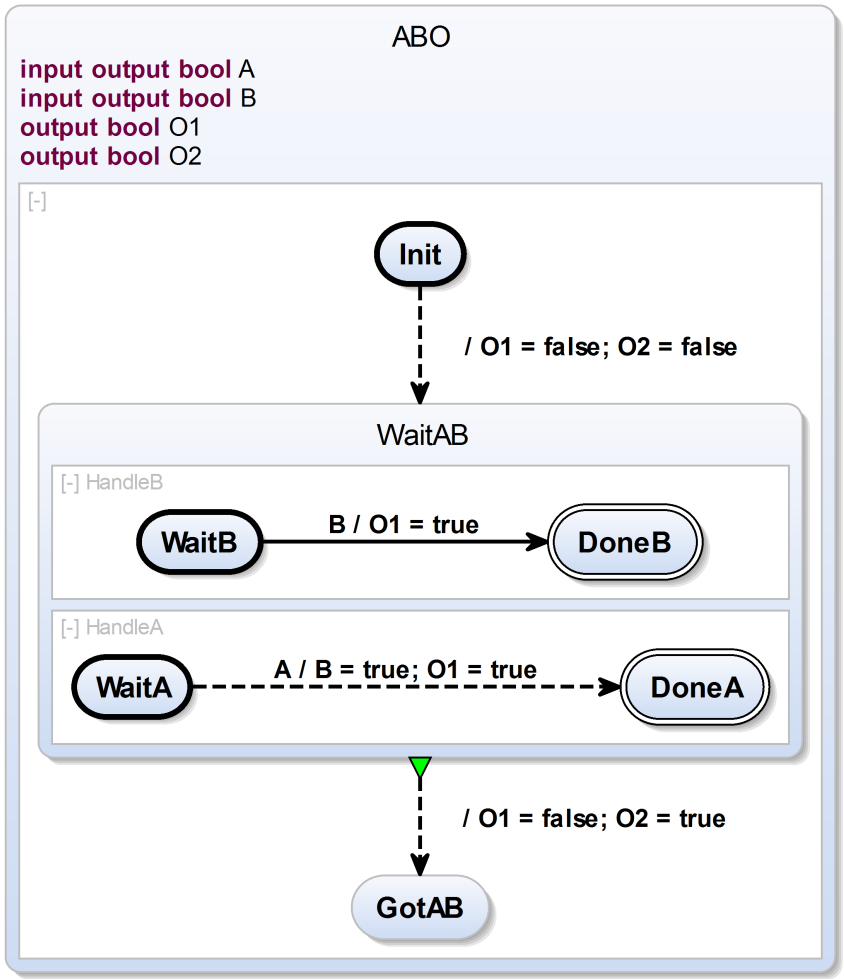

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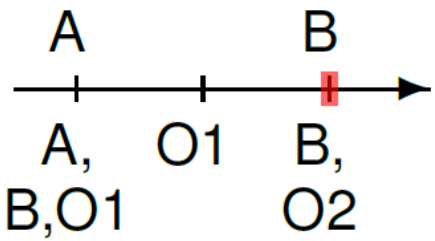
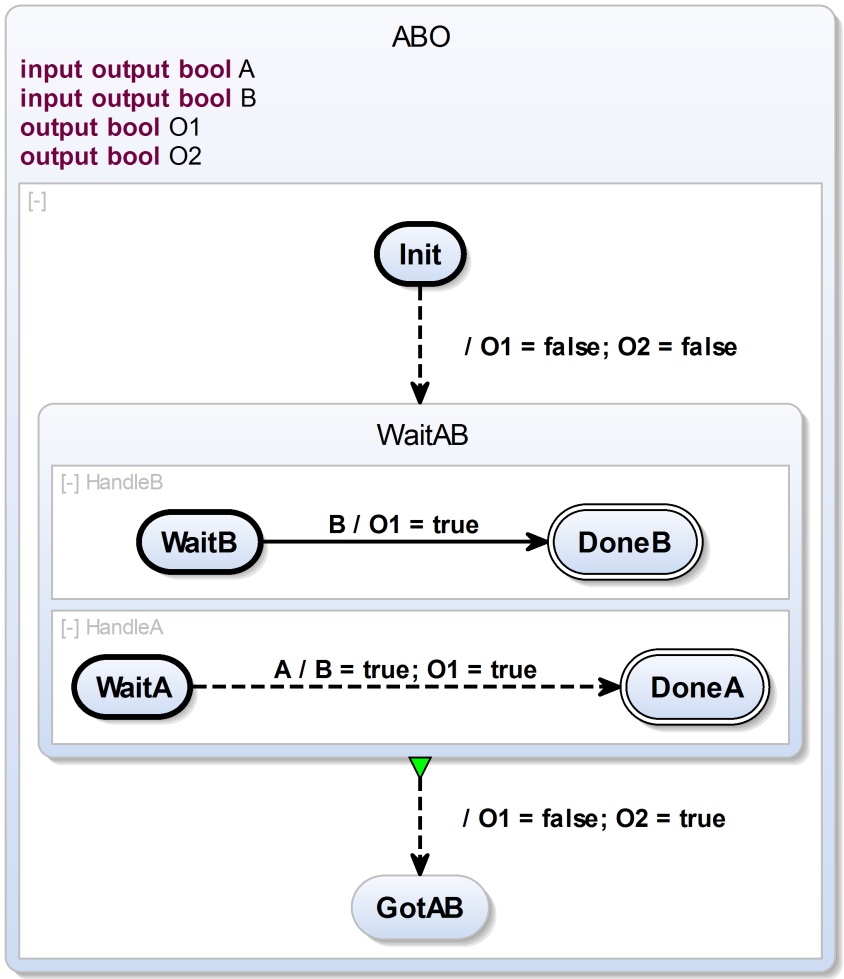


SCCharts Overview



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  SyncCharts syntax +
  Seqentially Constructive semantics
- *Hello World* of Sequential Constructiveness: **ABO**
  - Variables instead of signals
  - Behavior (briefly)
    1. Initialize
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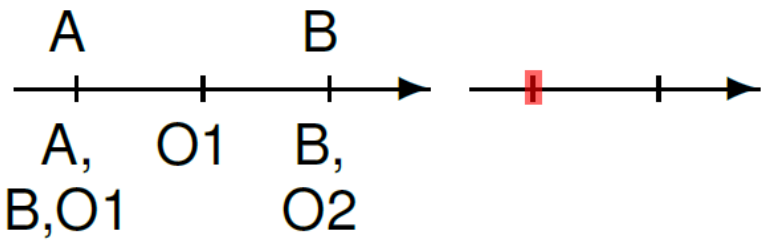

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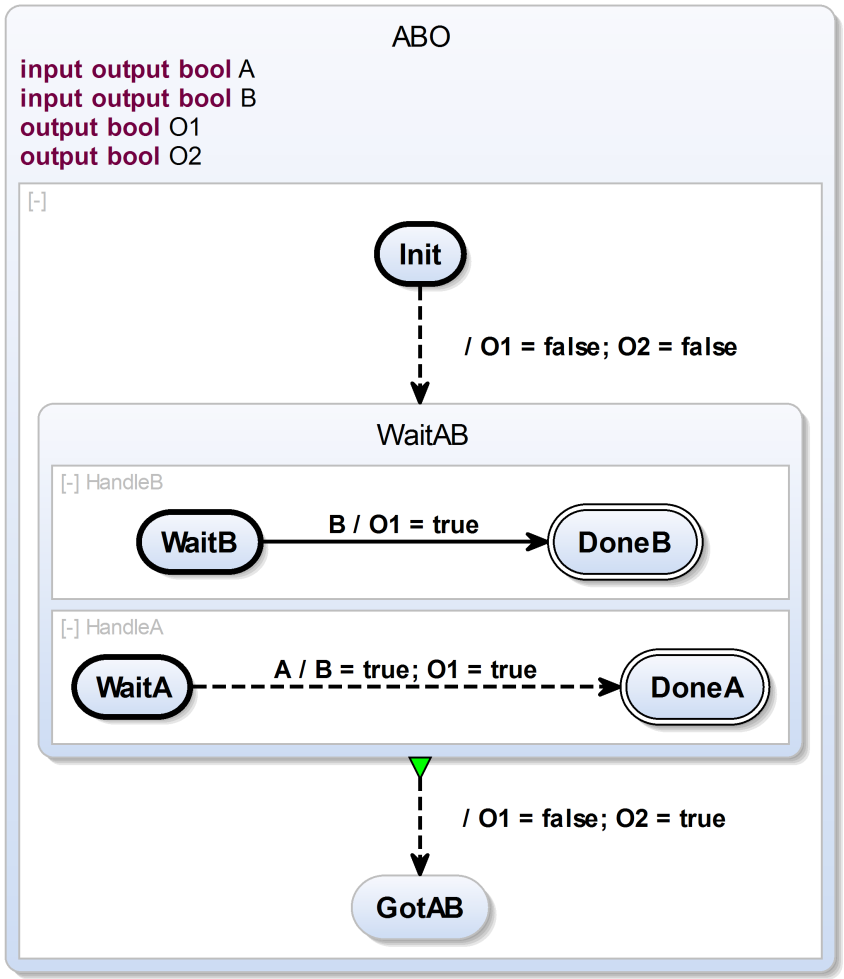

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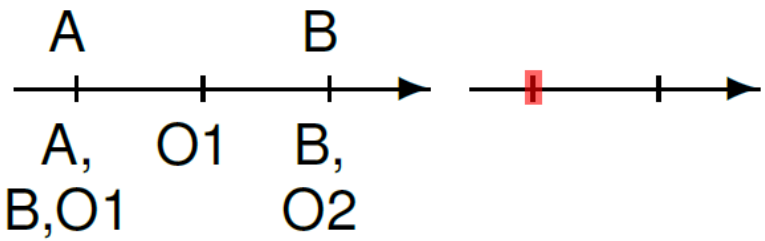

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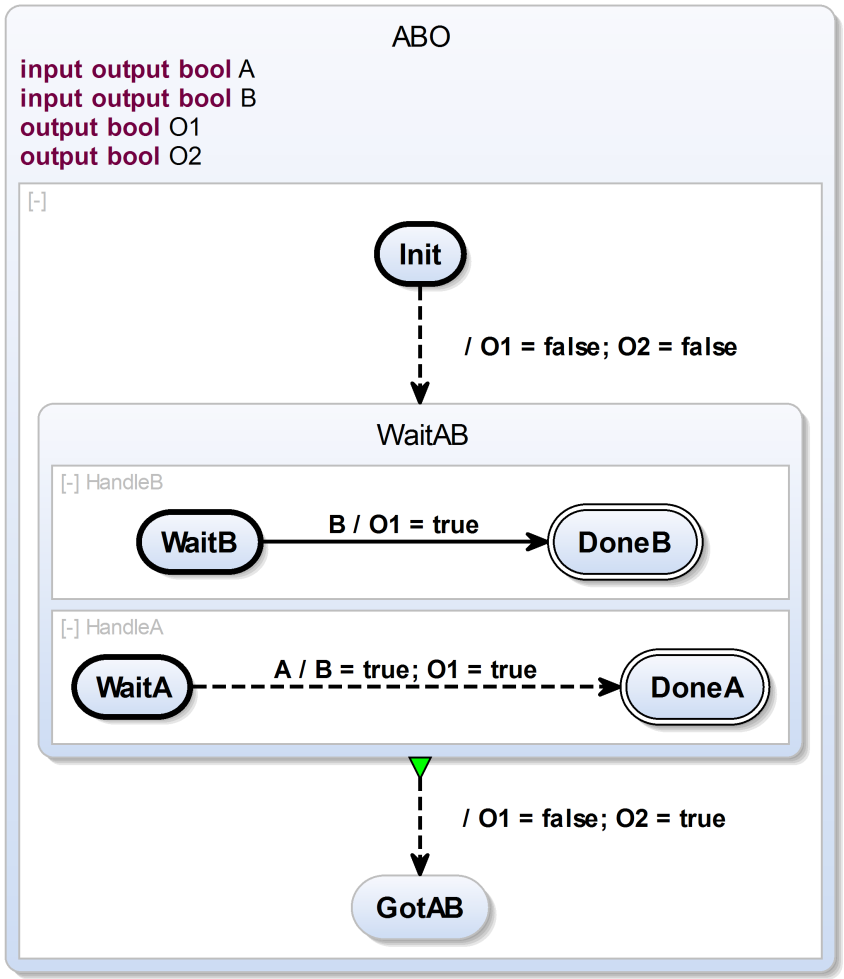

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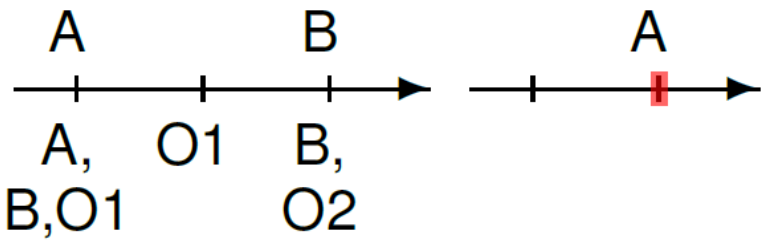

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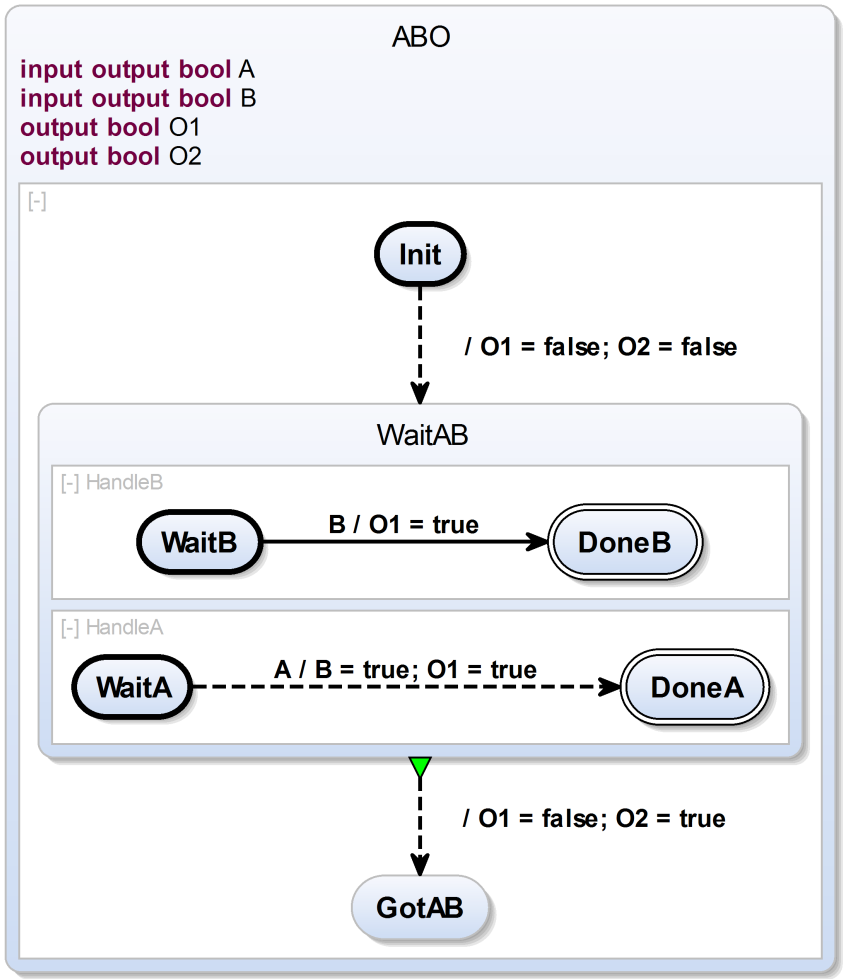

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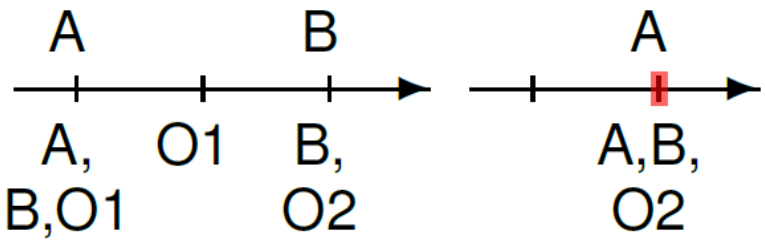
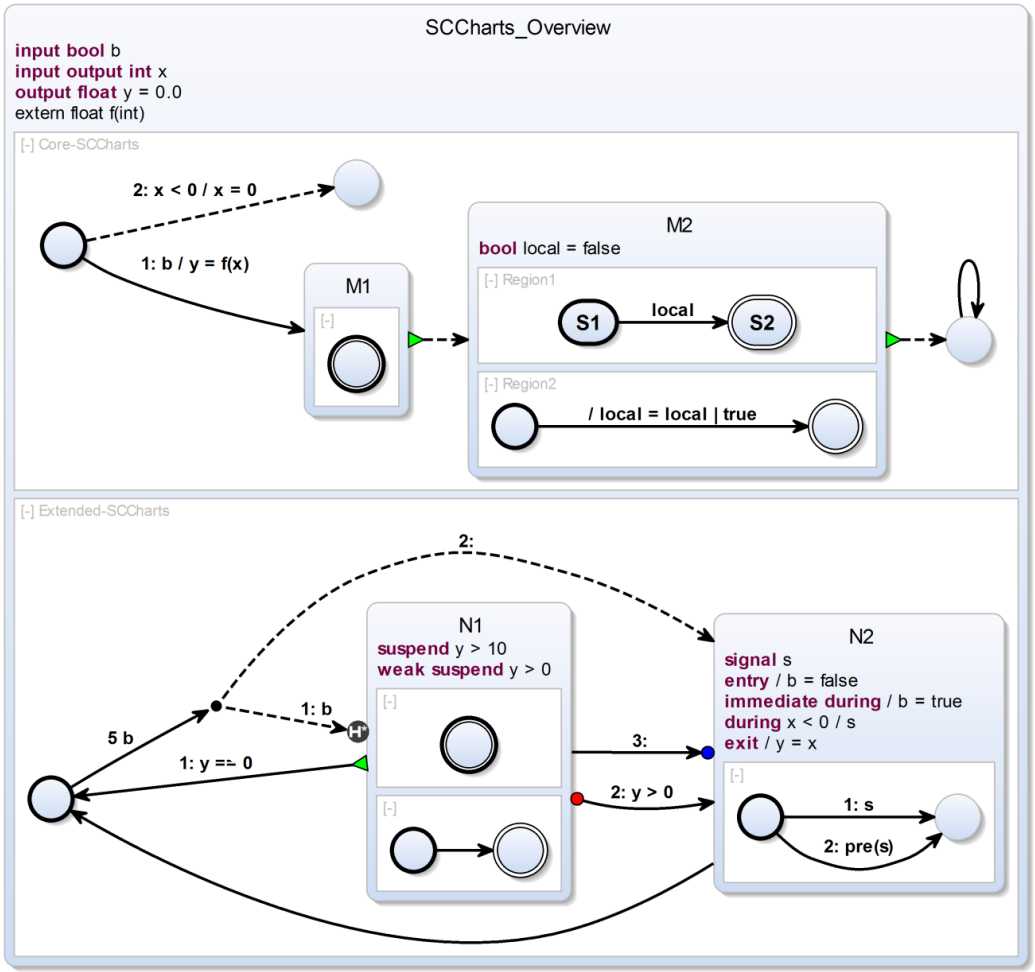
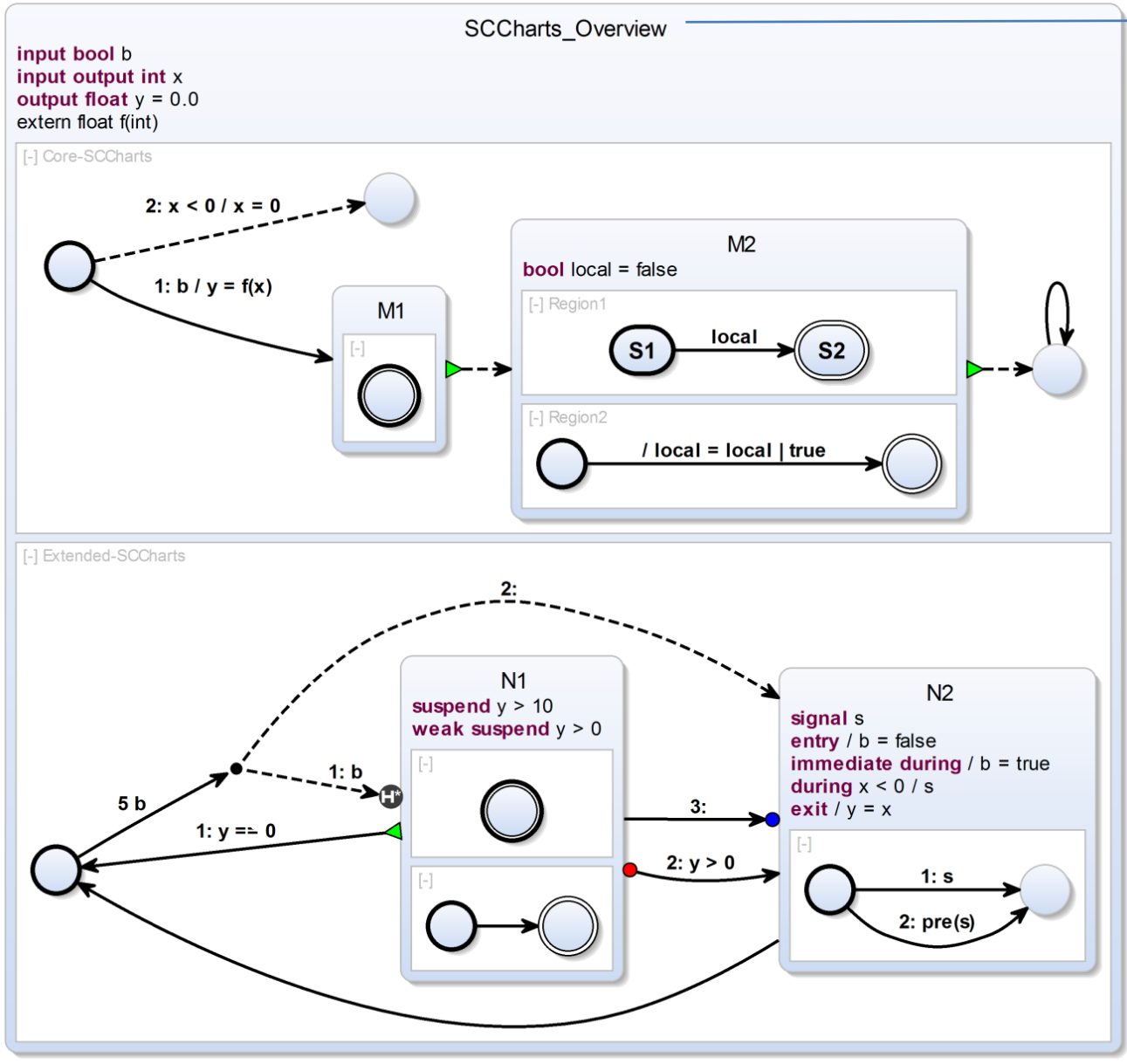


SCCharts — Features

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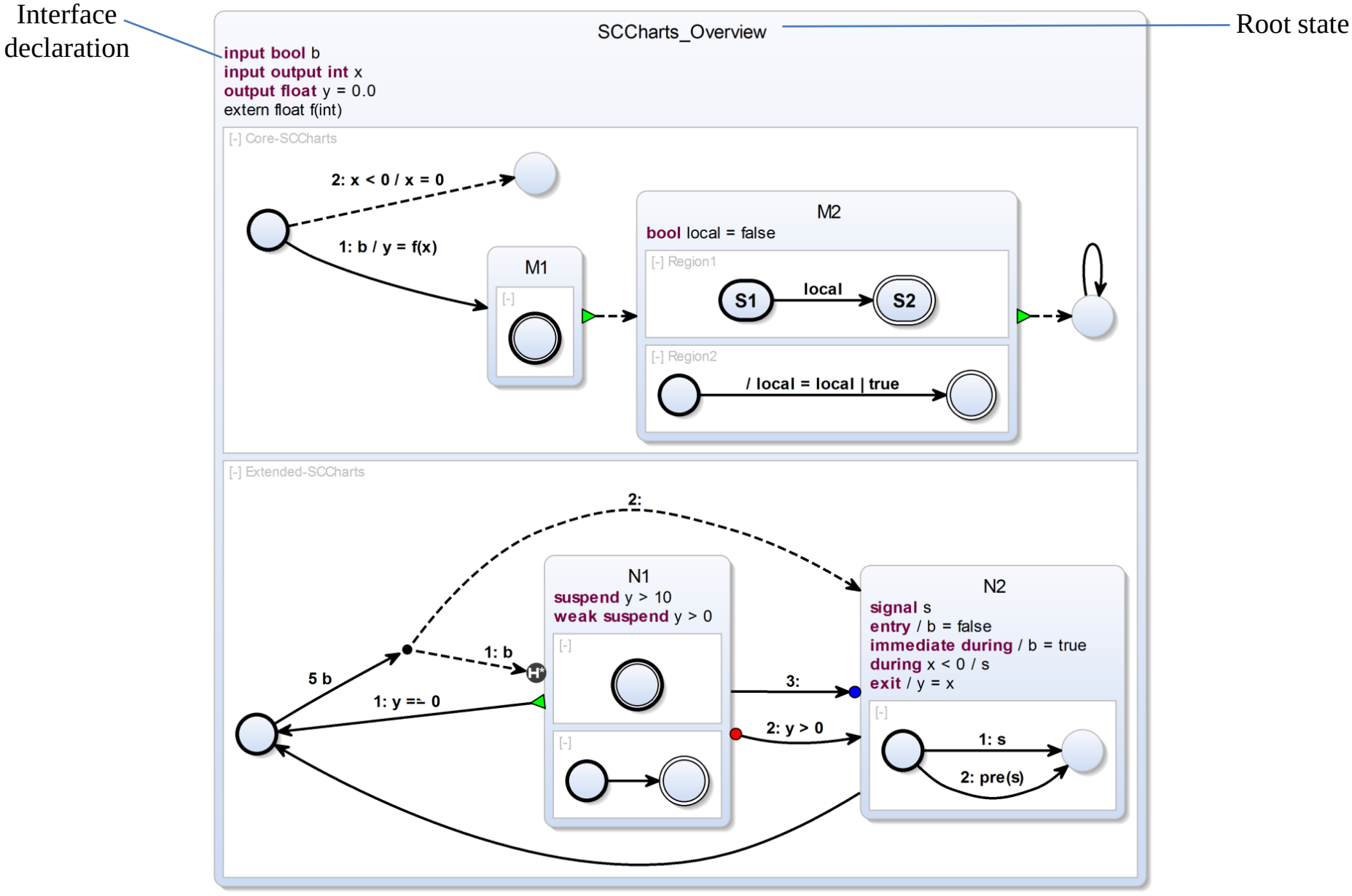
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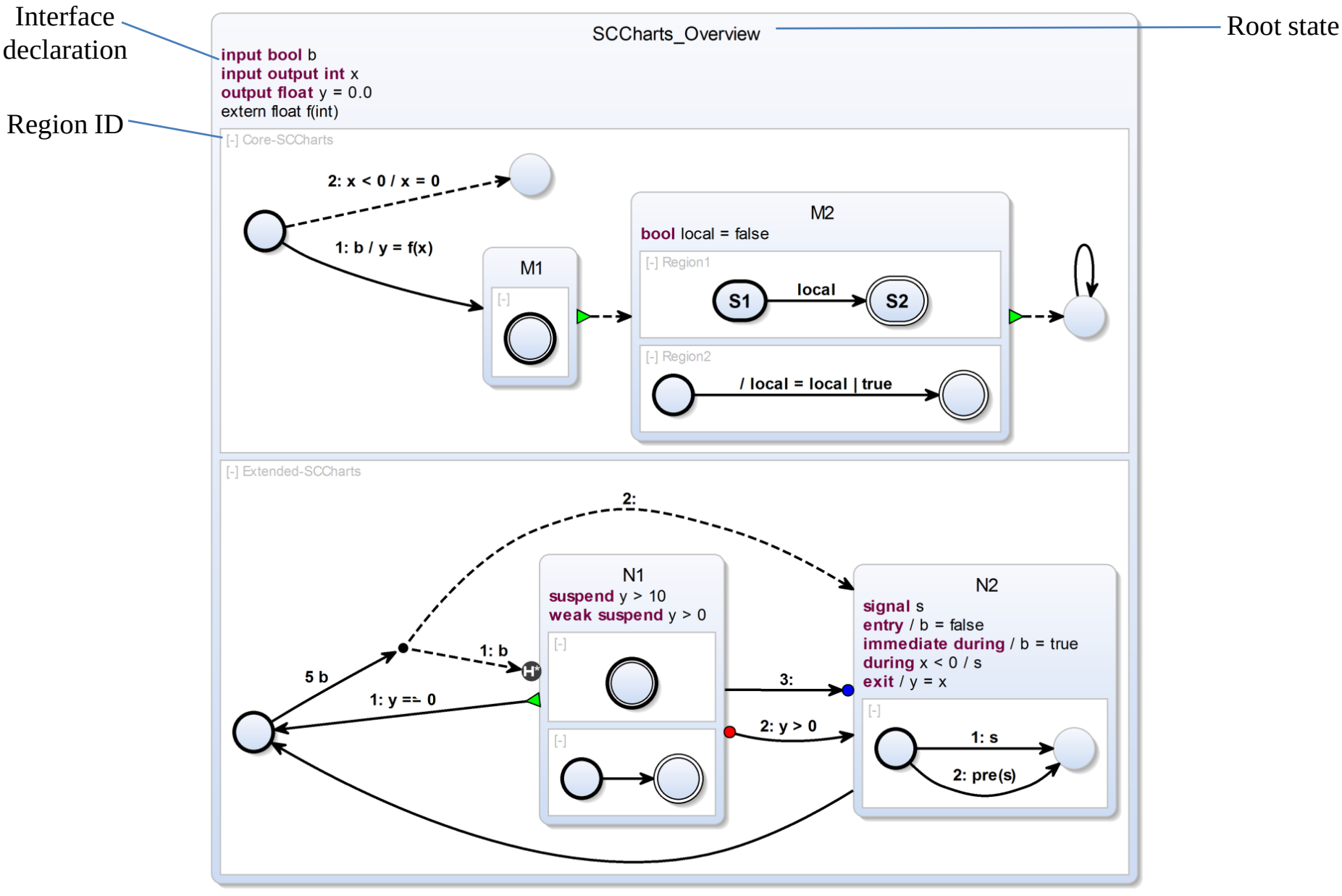
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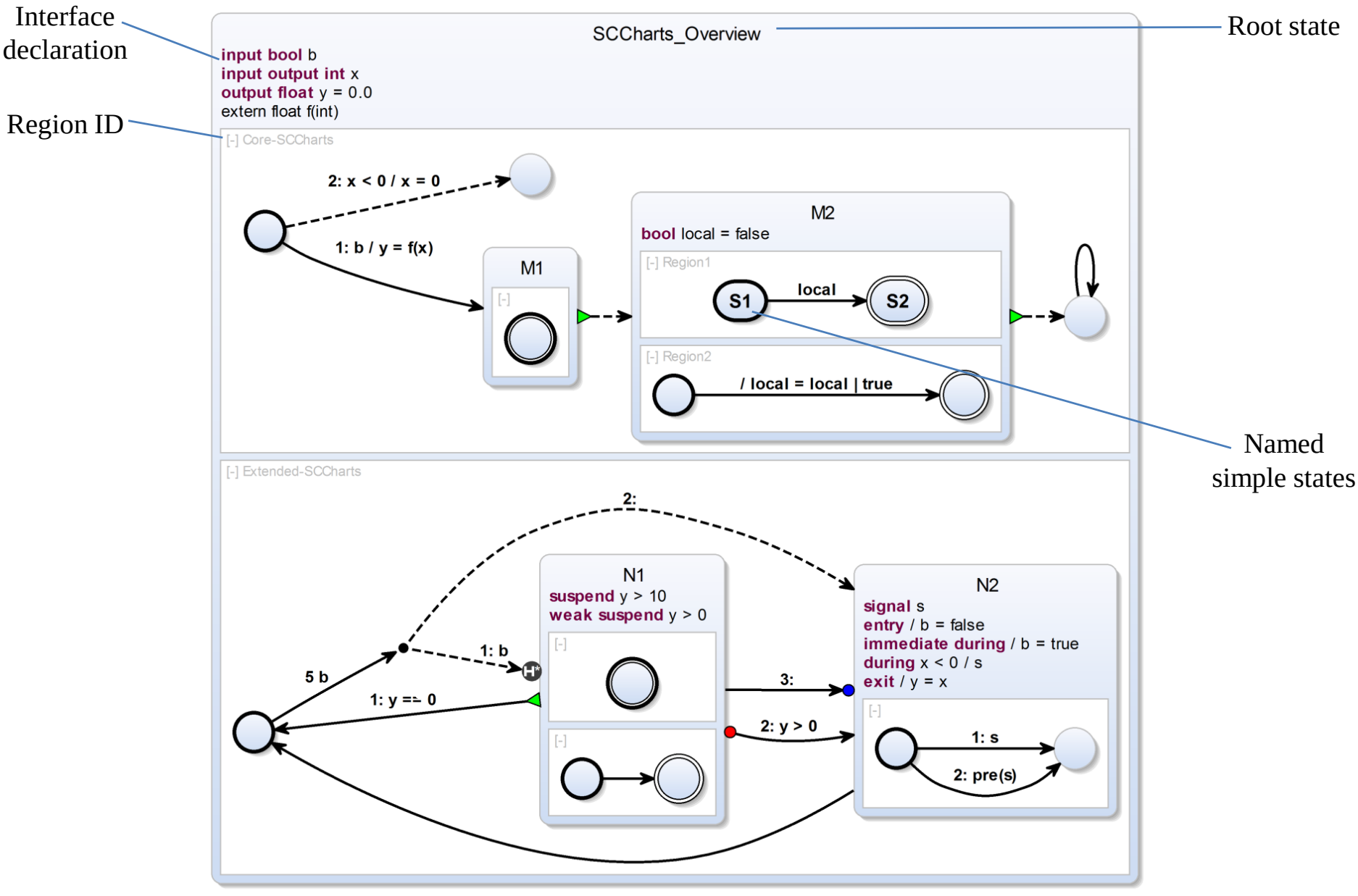
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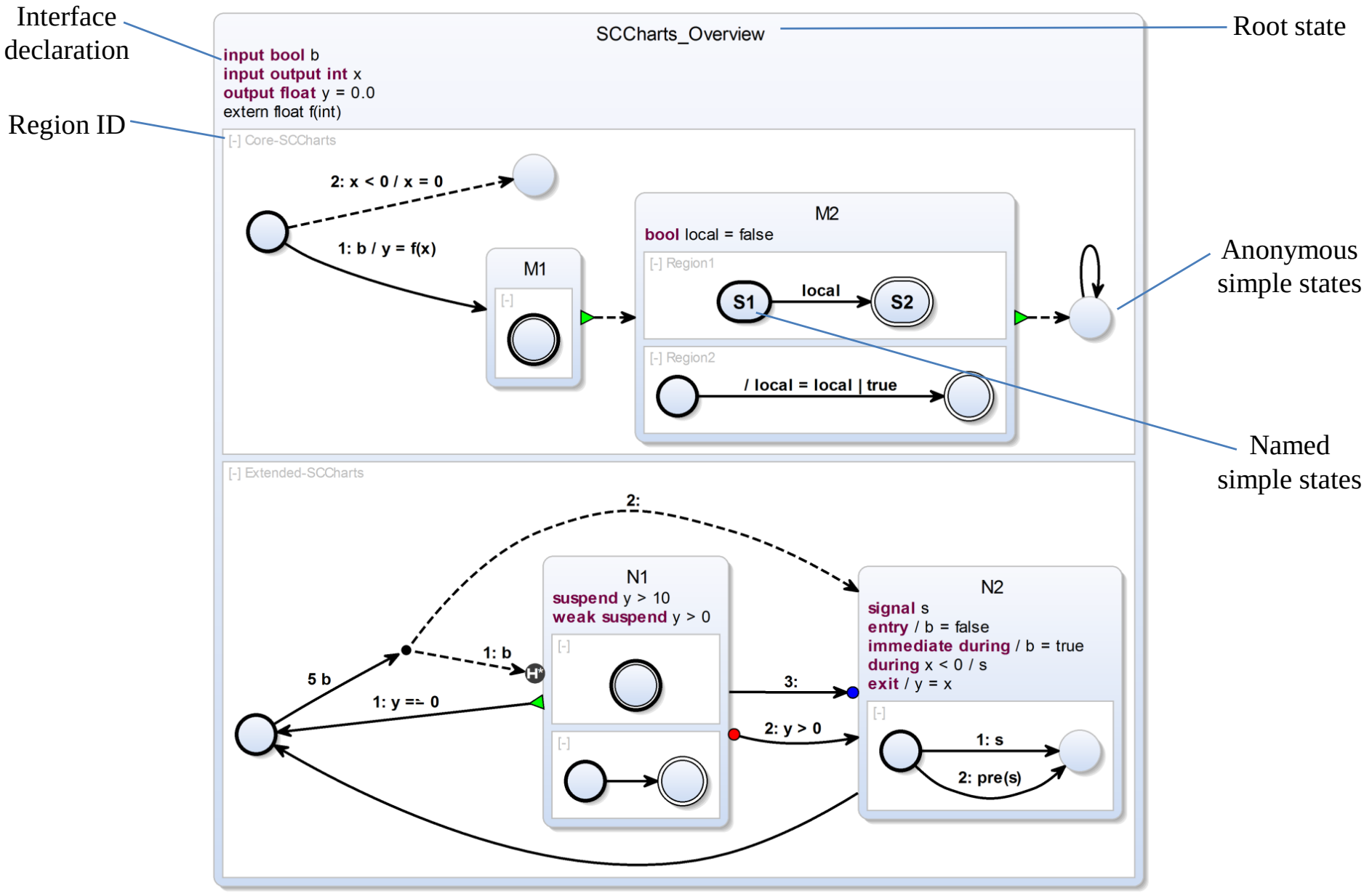
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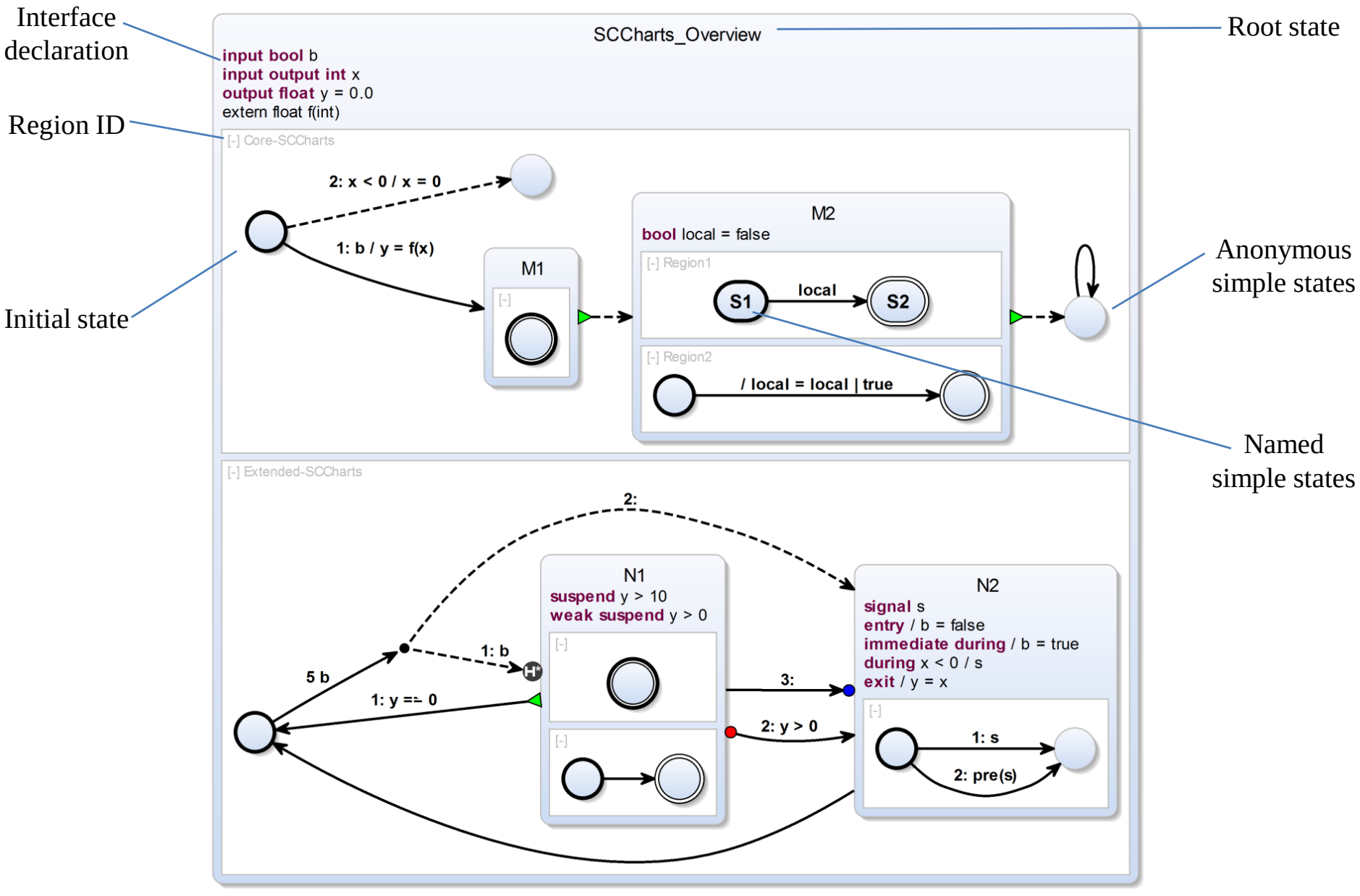
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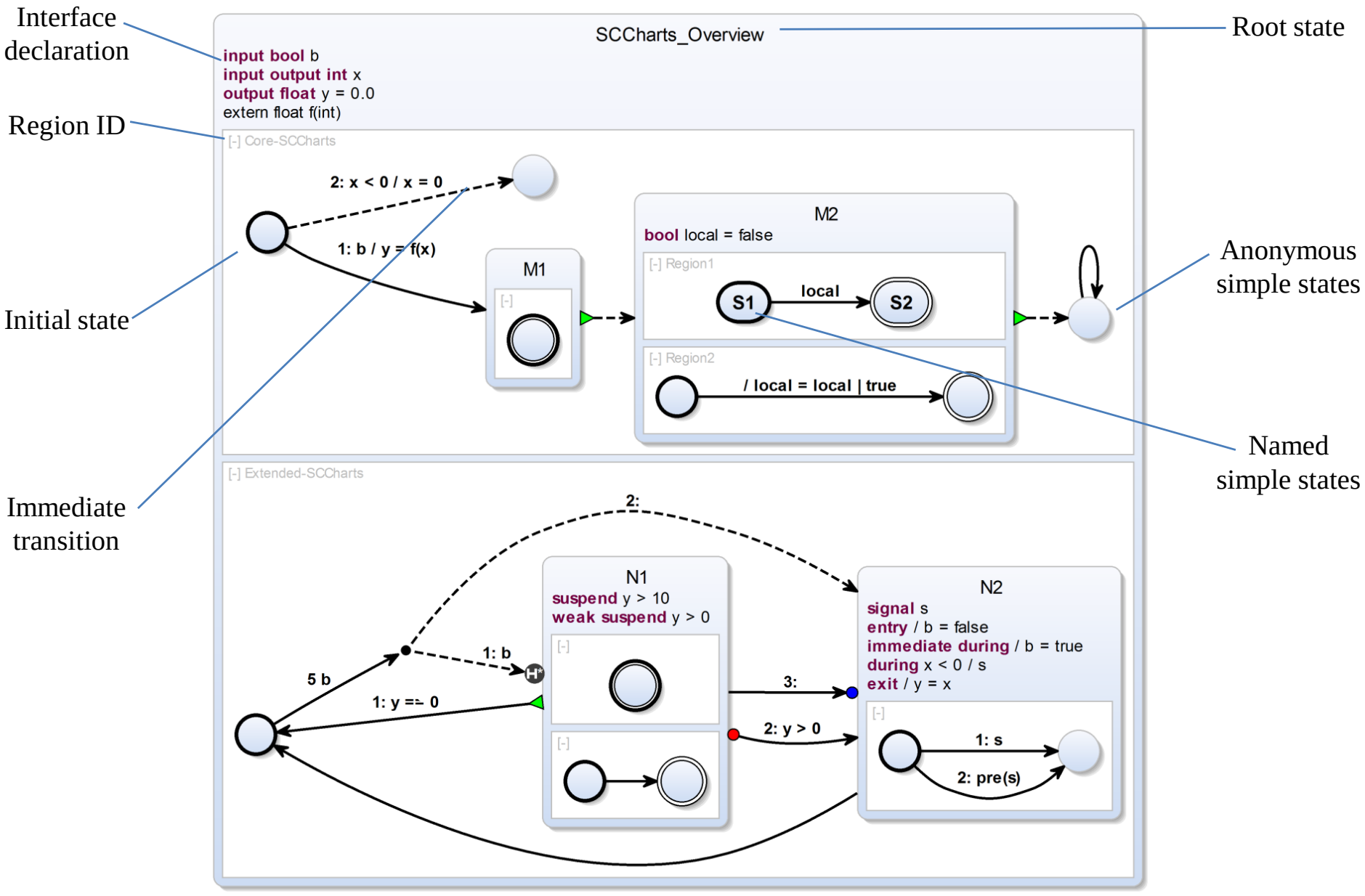
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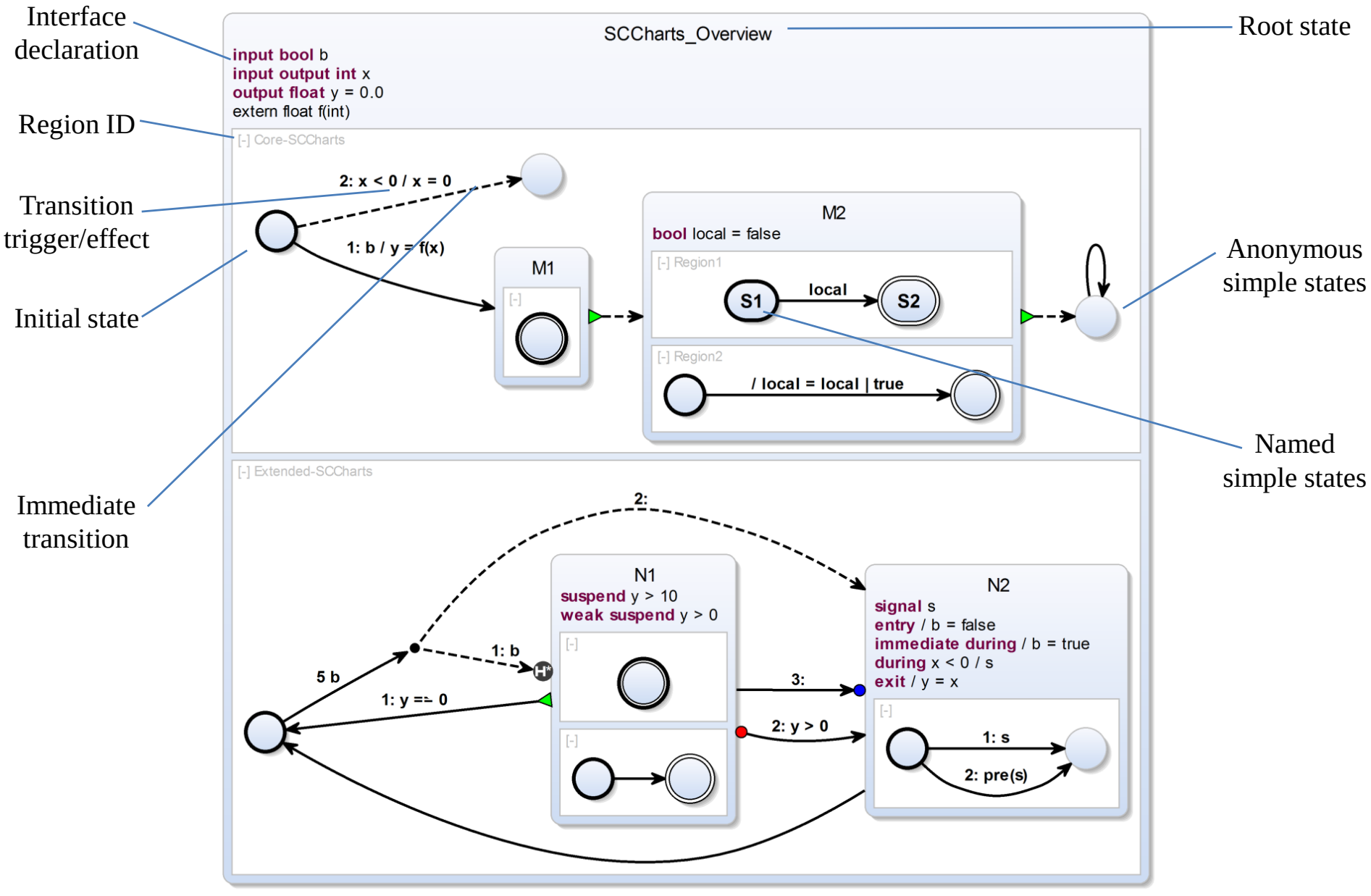
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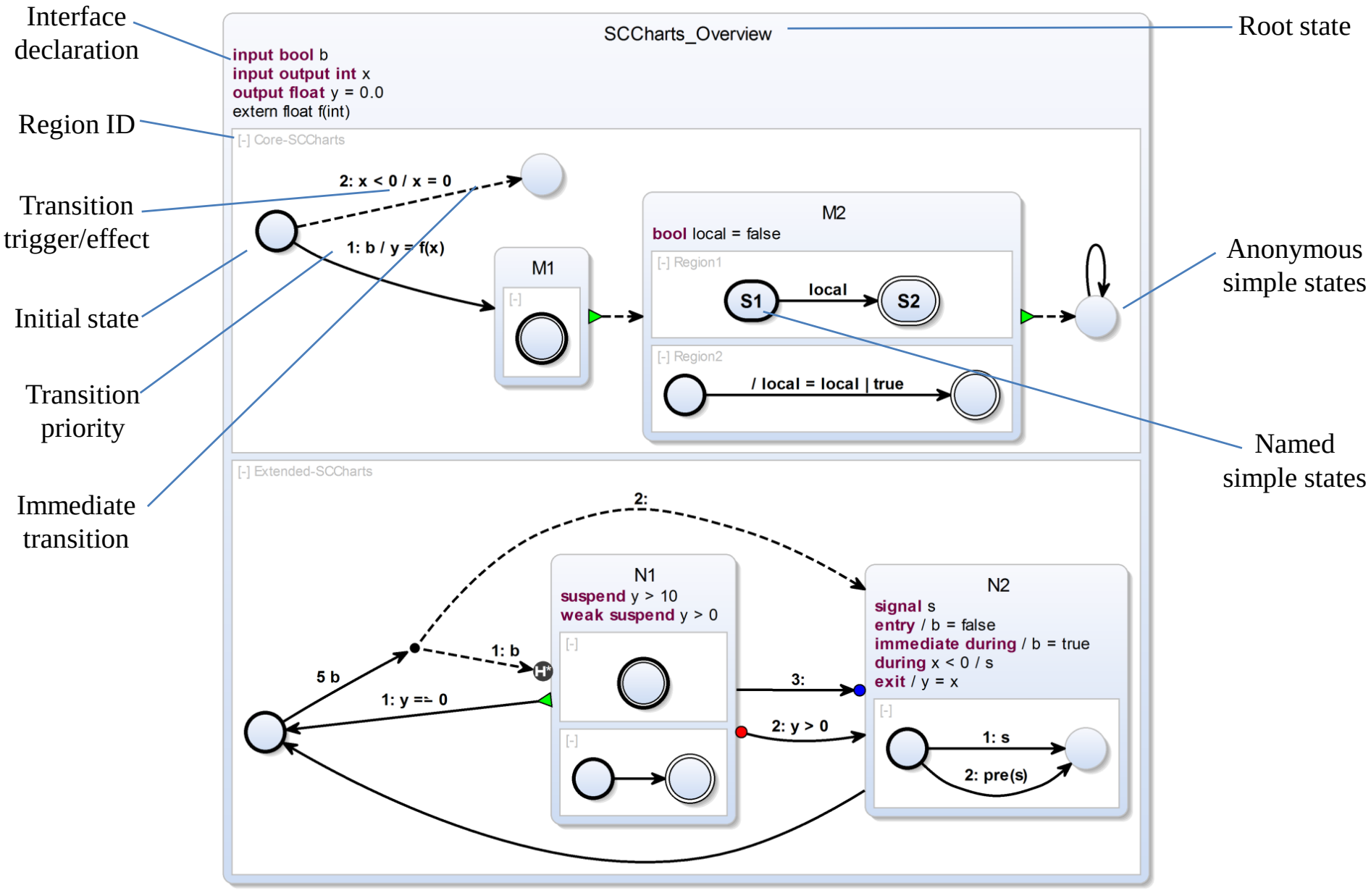
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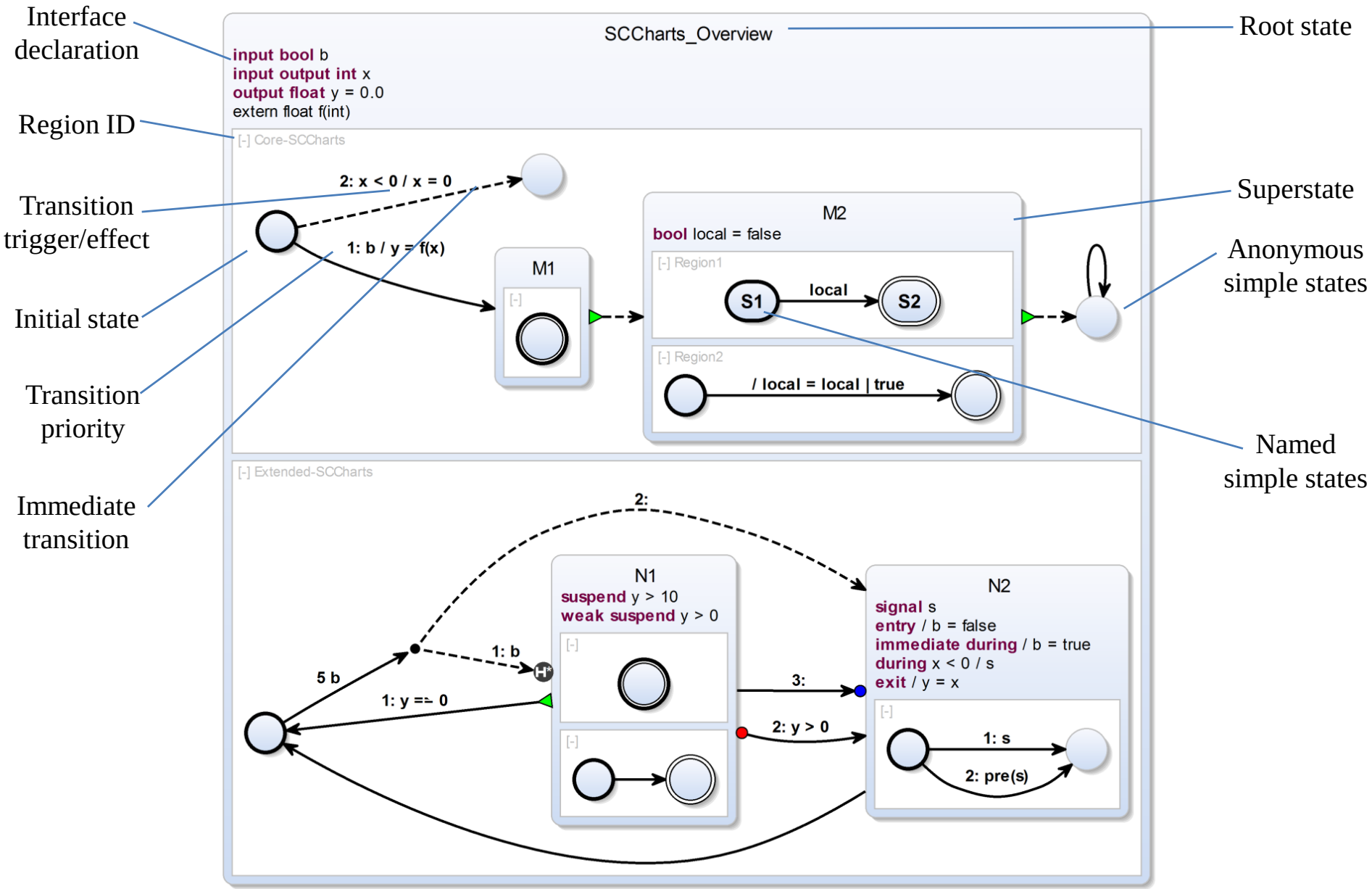
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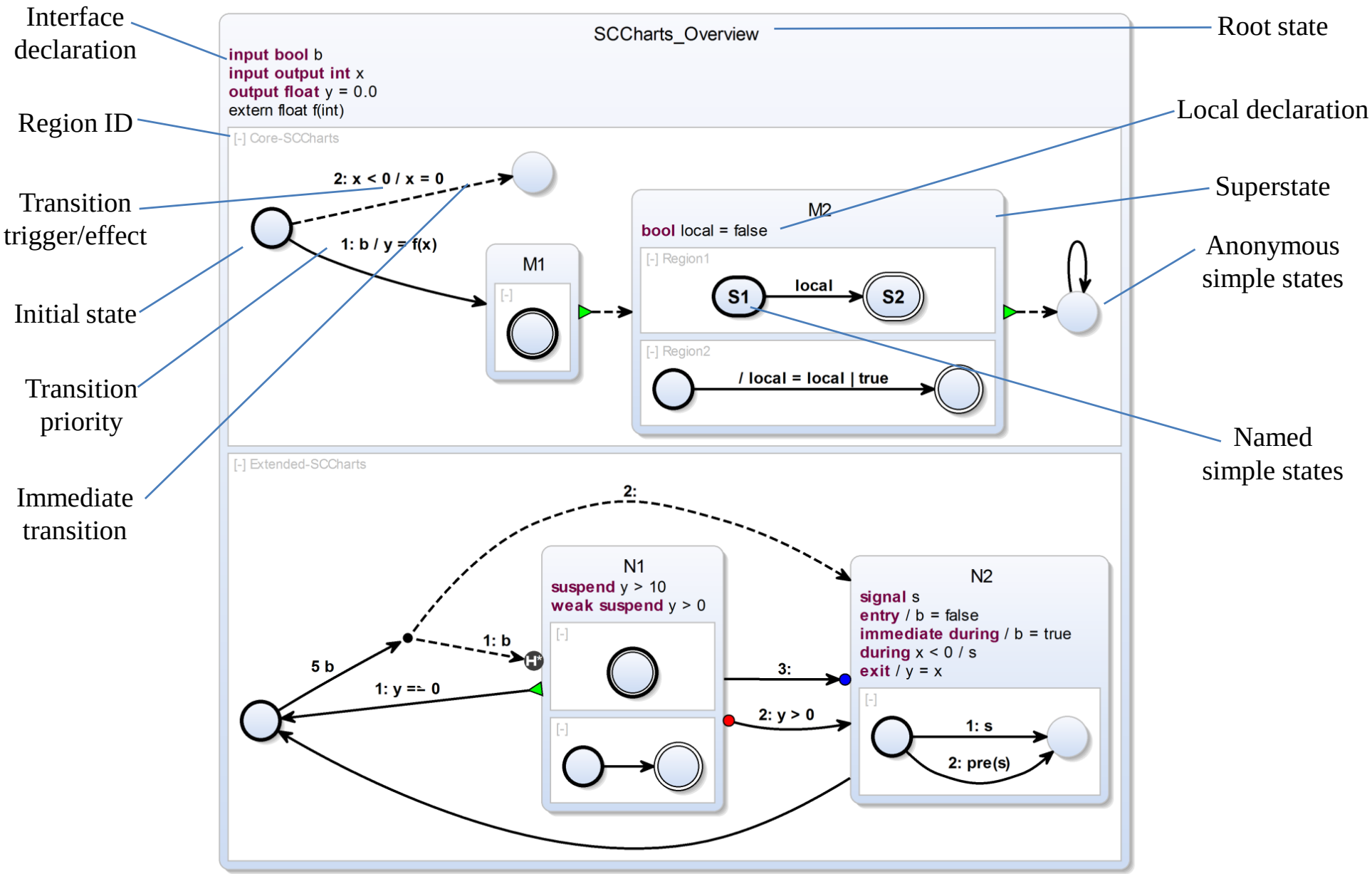
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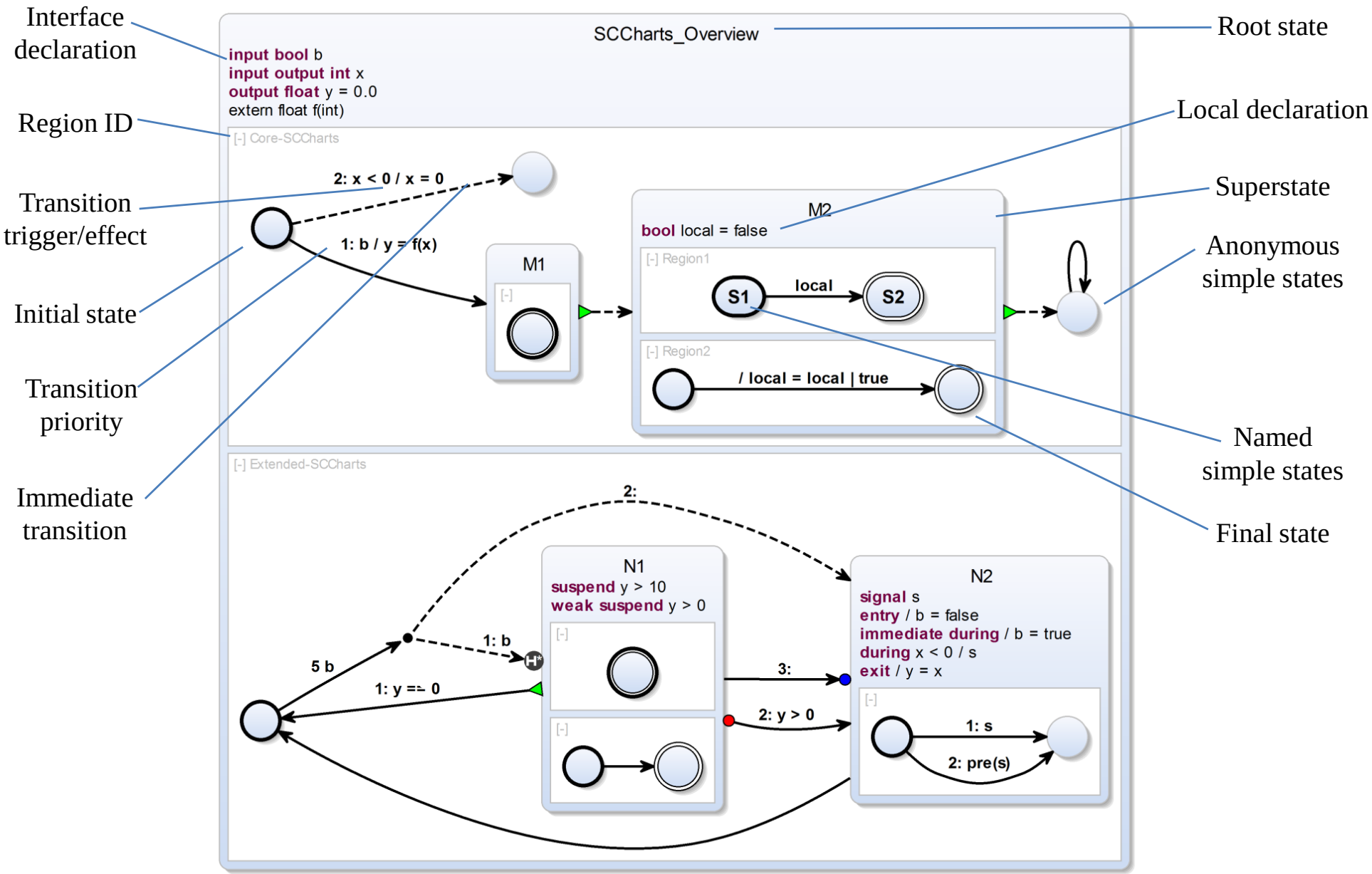
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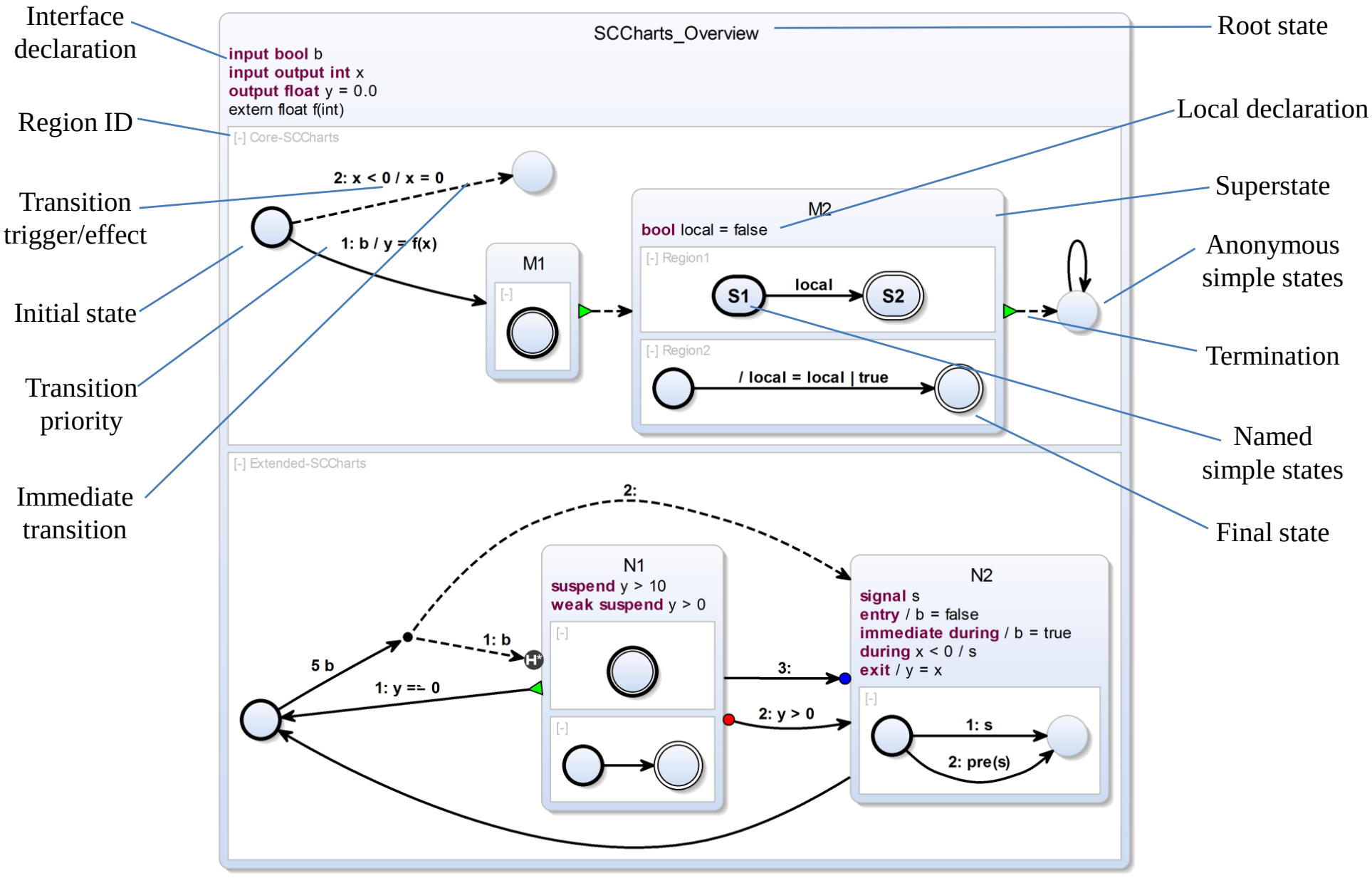
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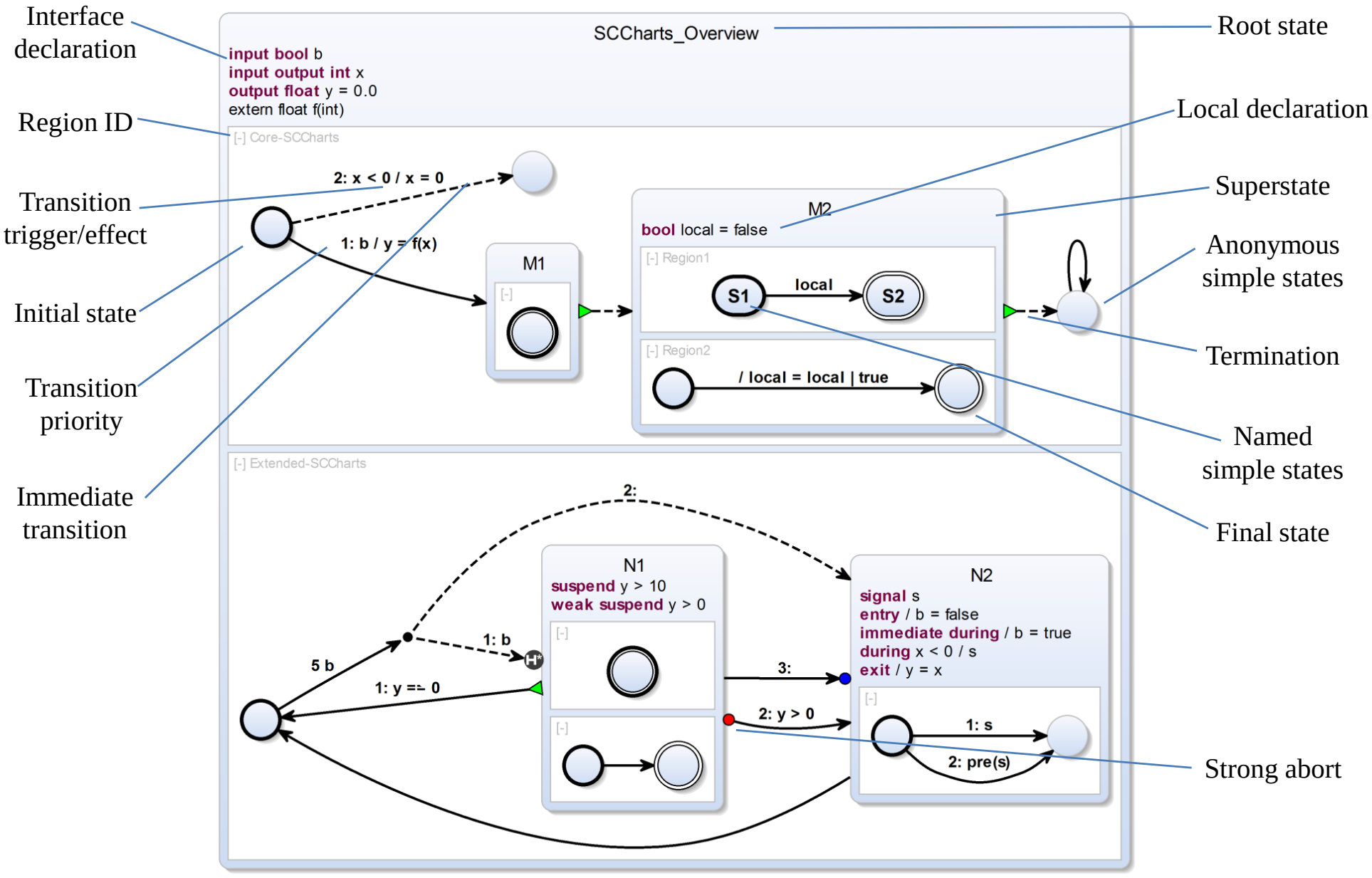
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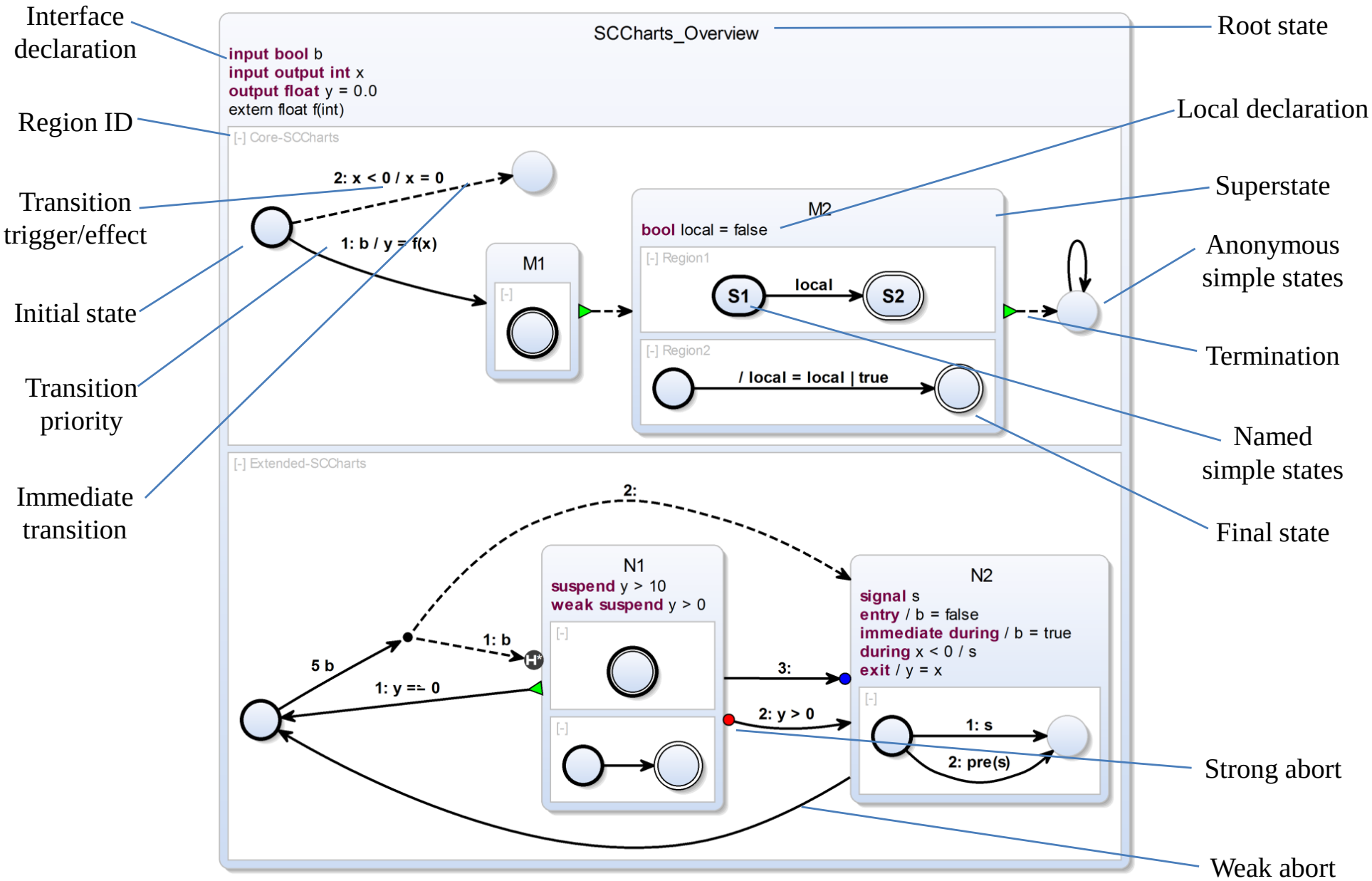
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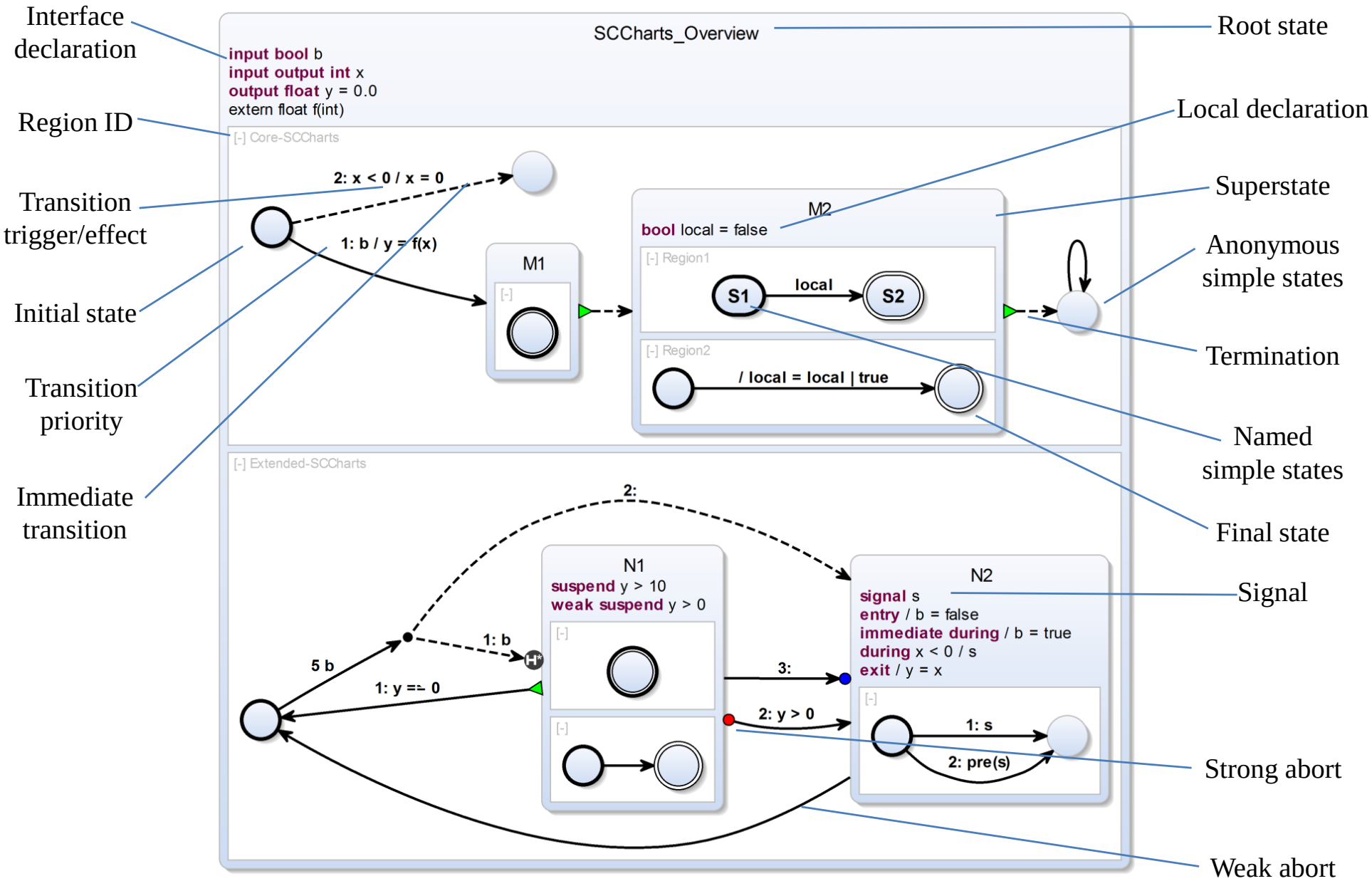
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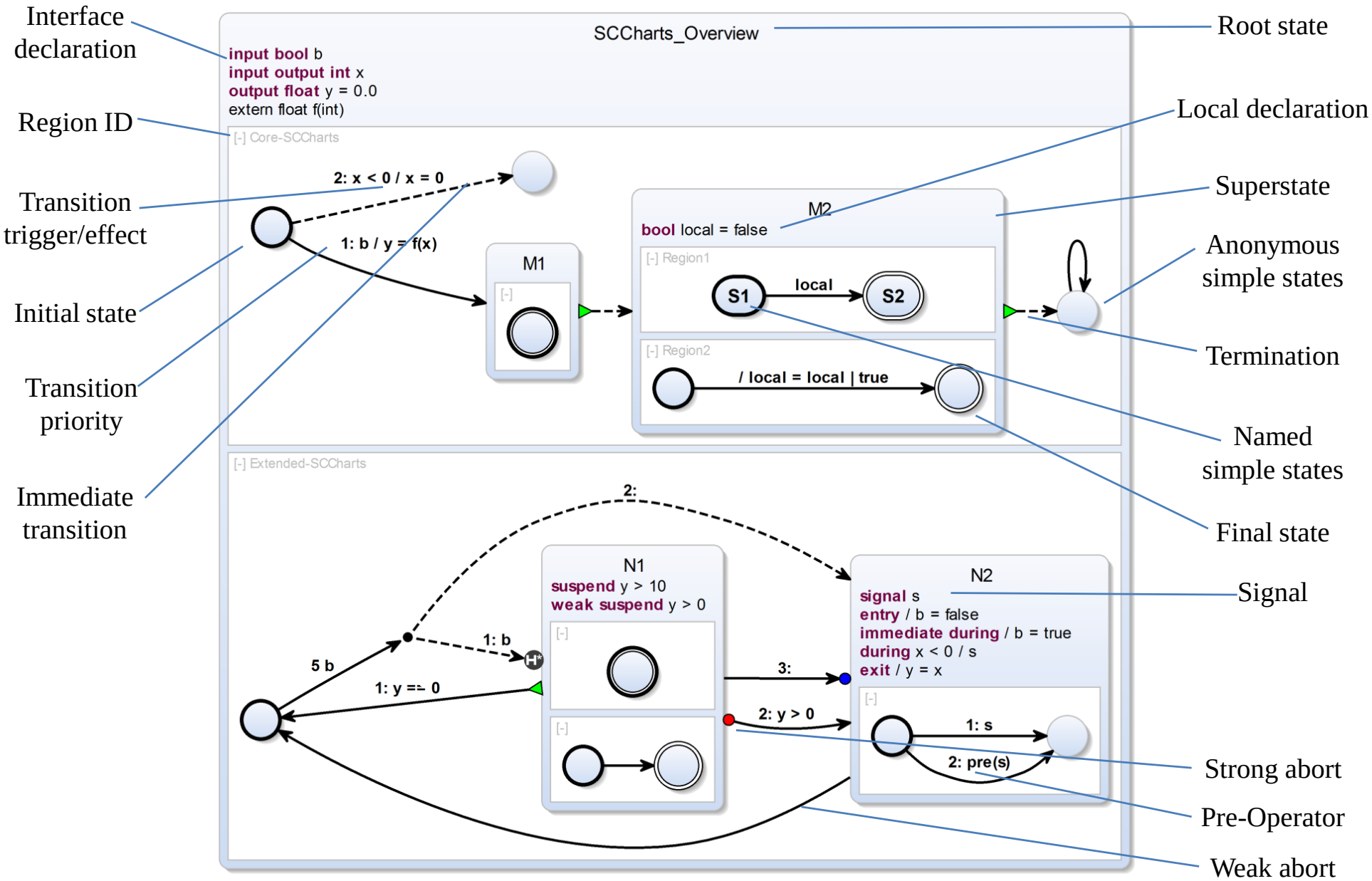
Termination
Named simple states
Final state
Signal
Strong abort
Weak abort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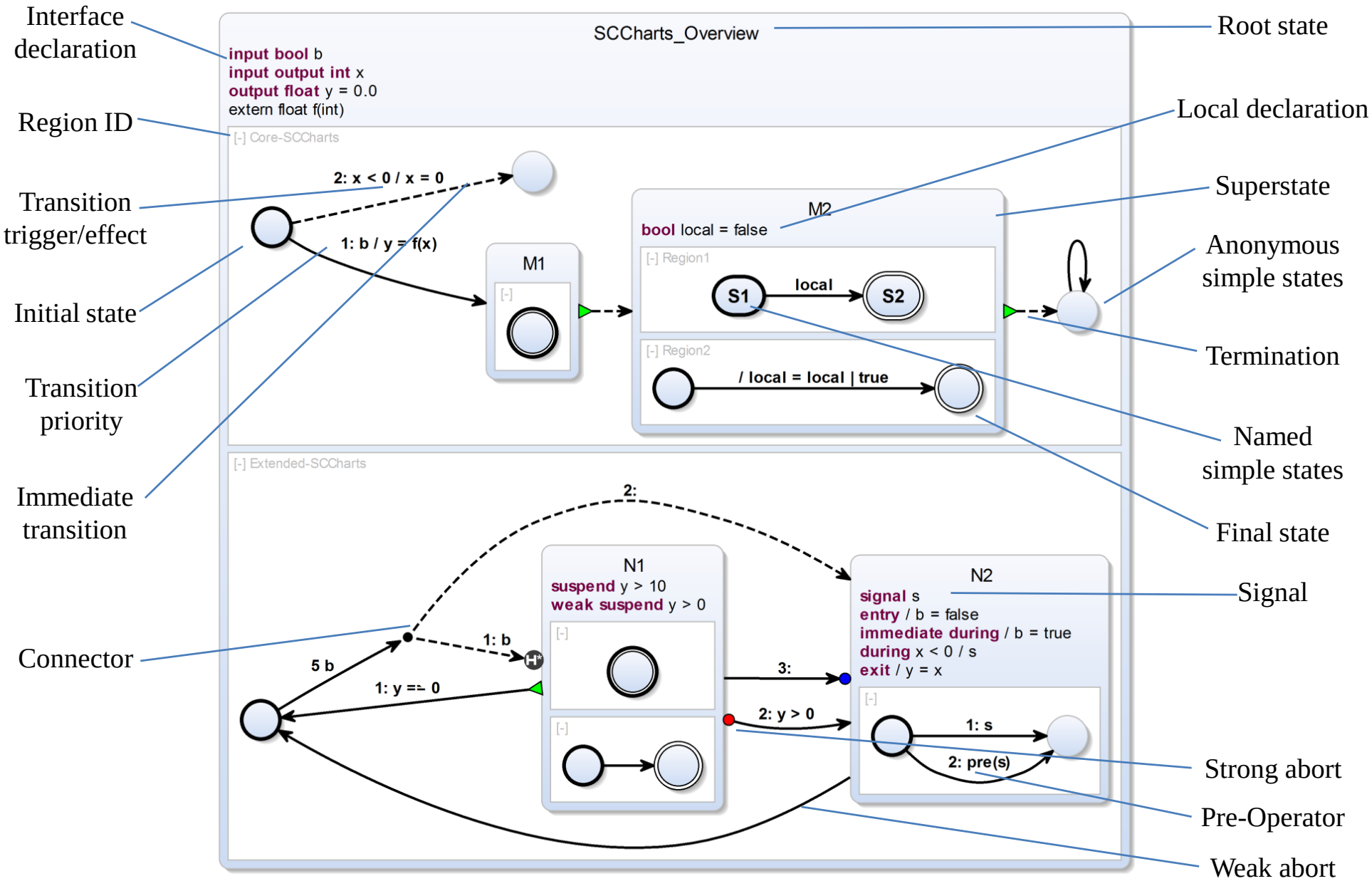
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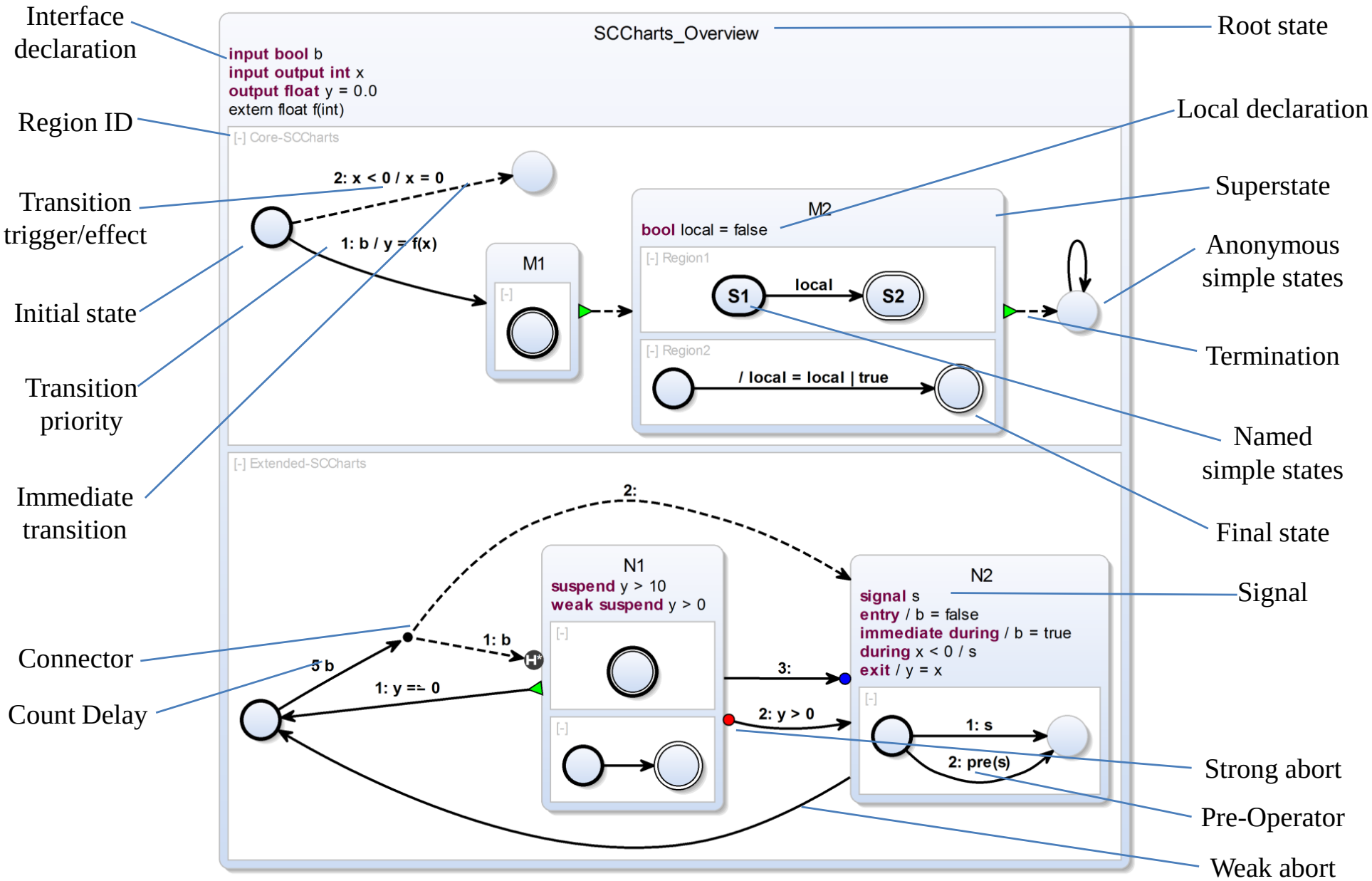
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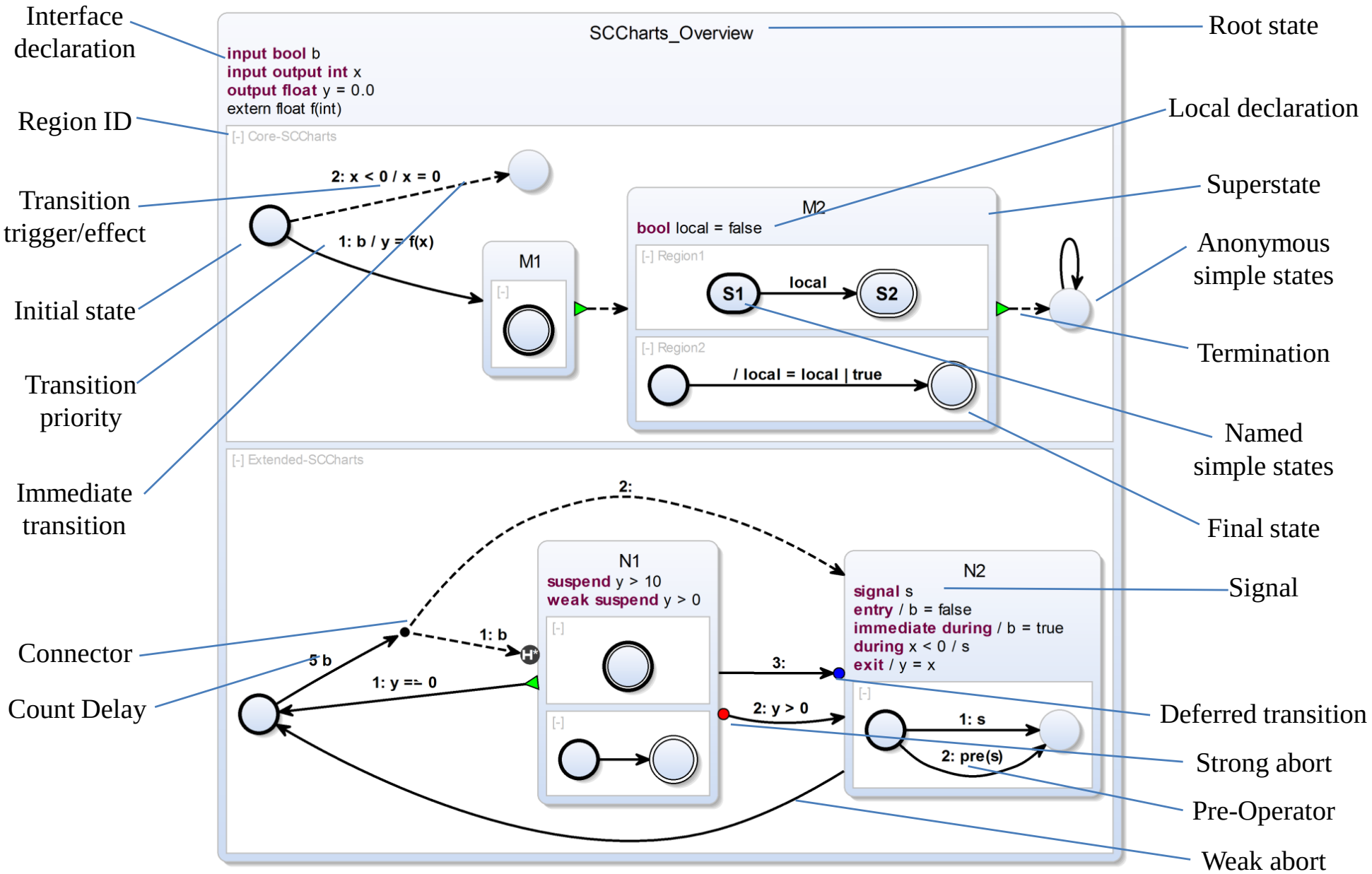
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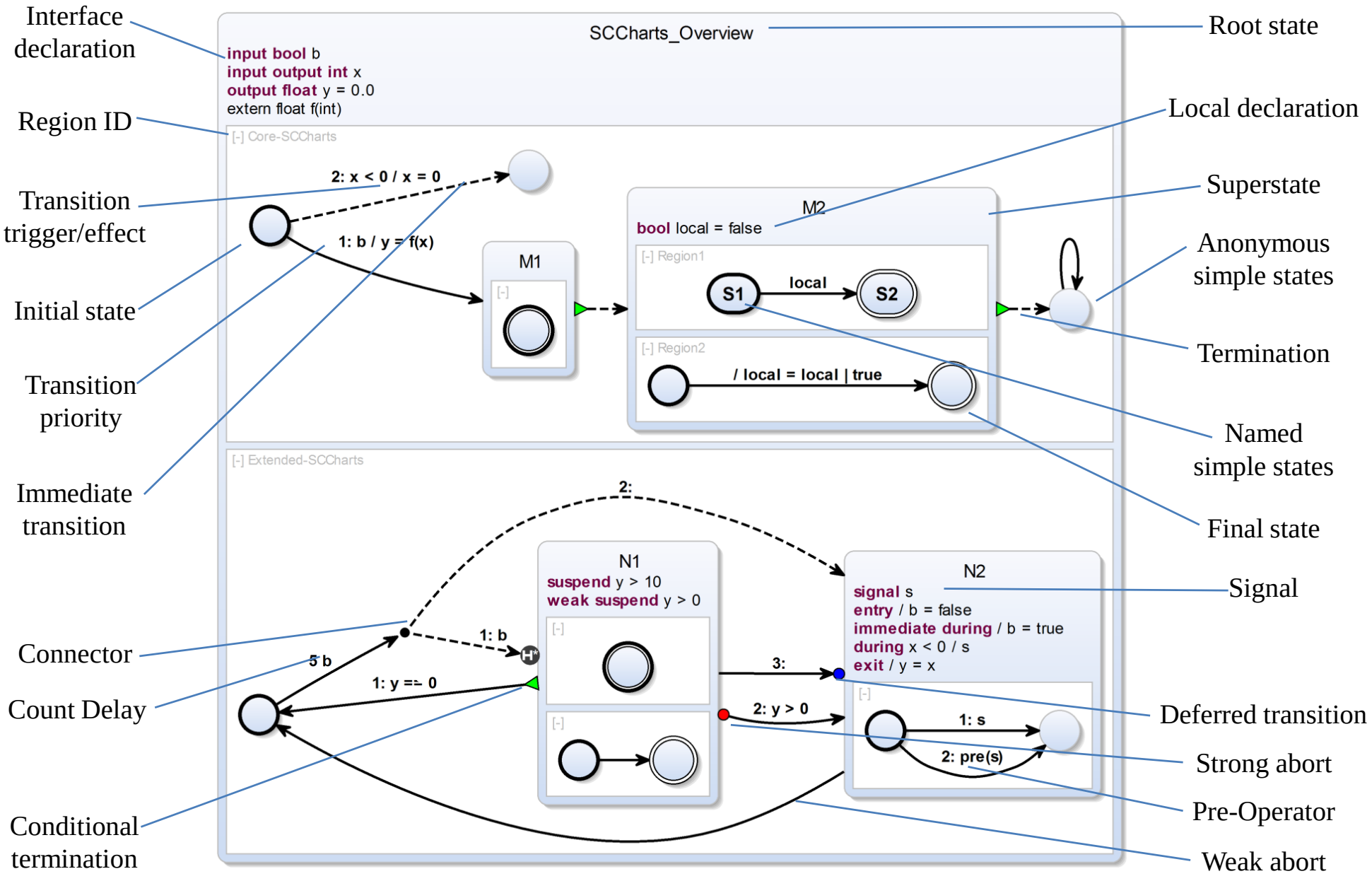
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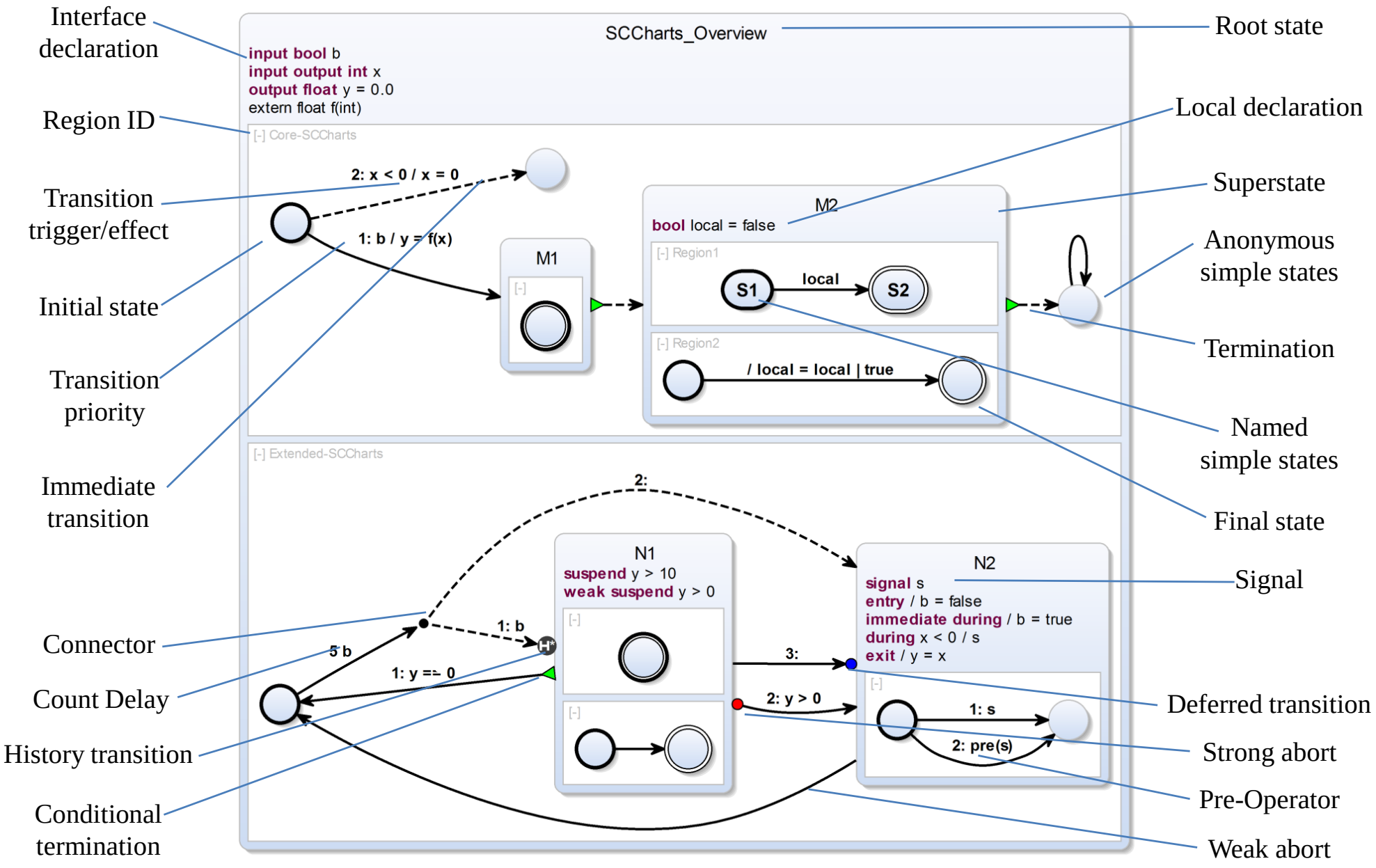
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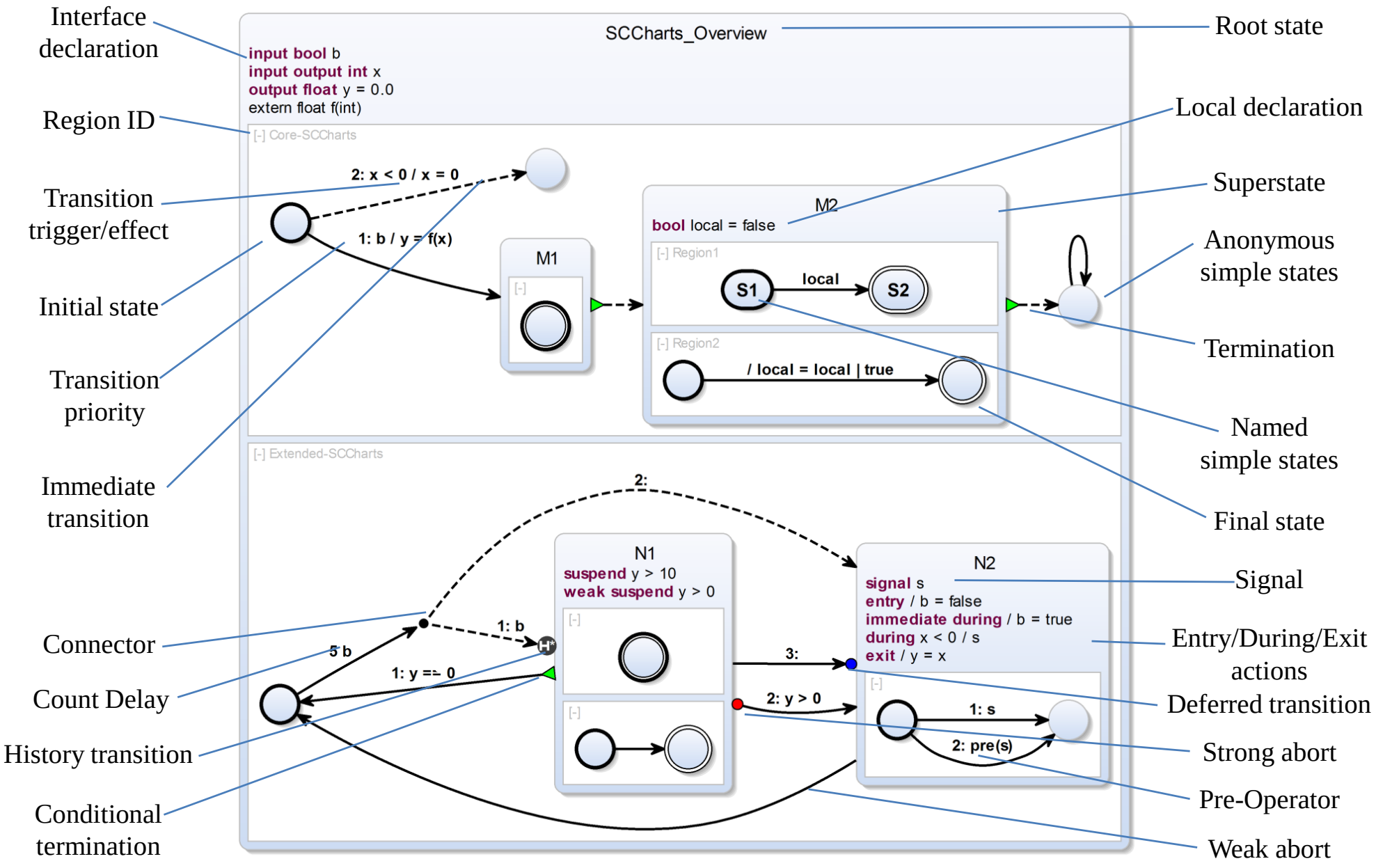
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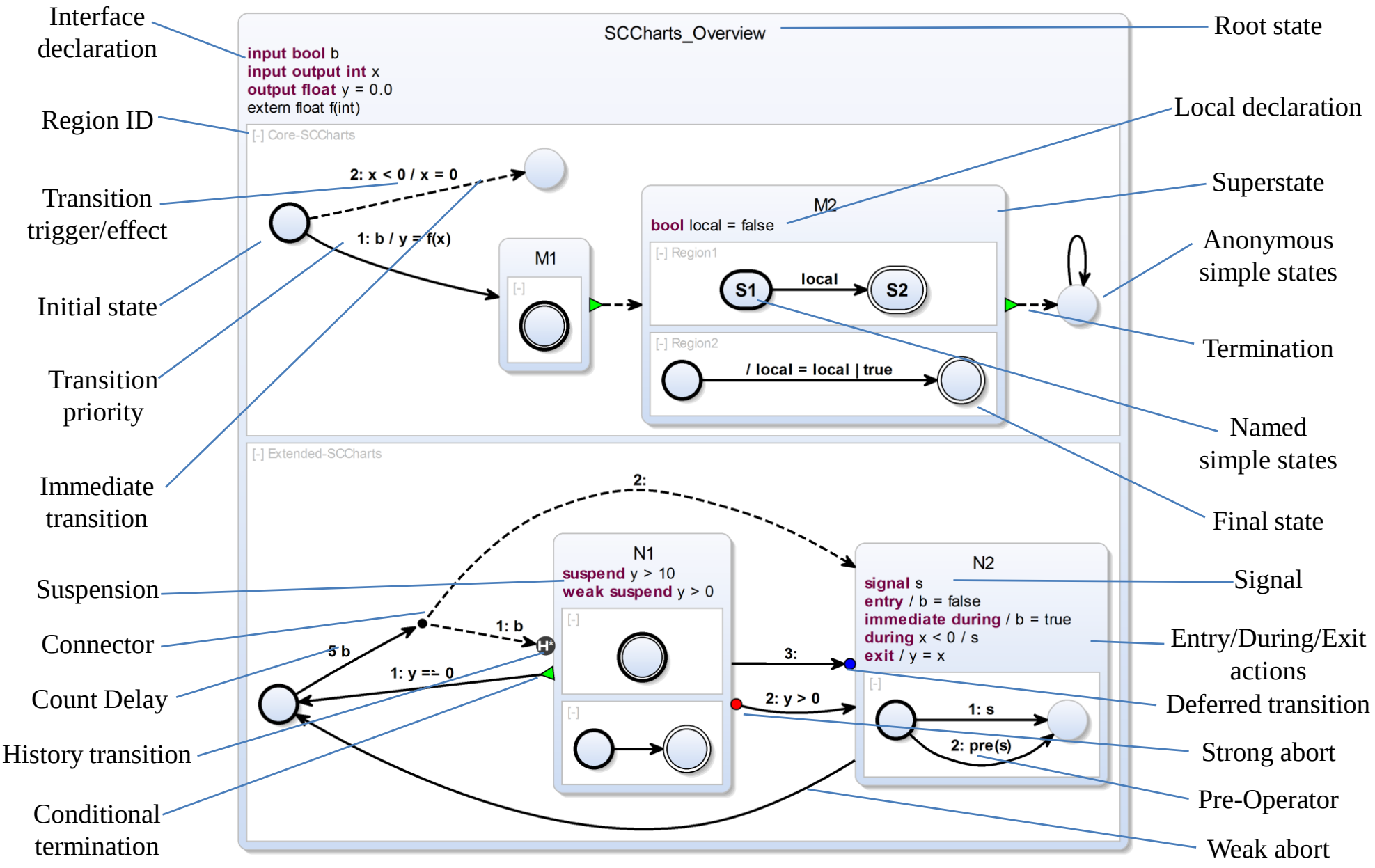
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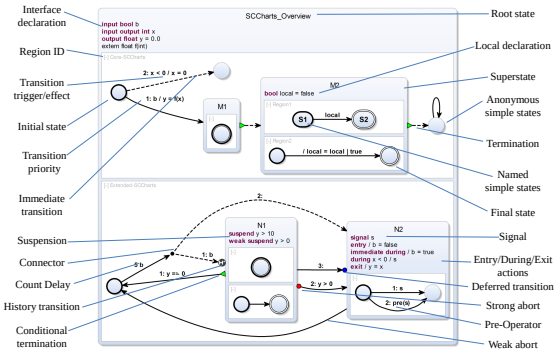
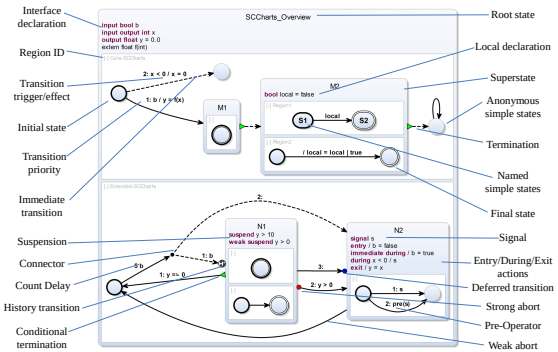
Motivation for Core SCCharts



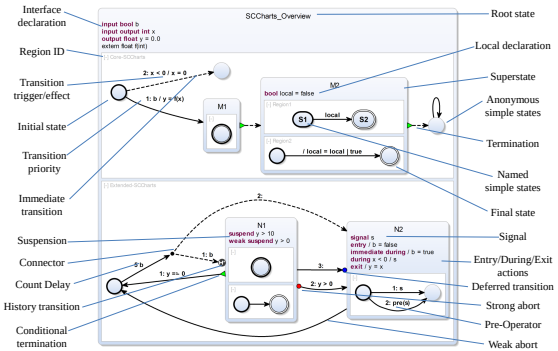
- **Observation I**

Motivation for Core SCCharts



- **Observation I**: Numerous features

Motivation for Core SCCharts



- **Observation I**: Numerous features
  - ☺ Compactness / readability of models

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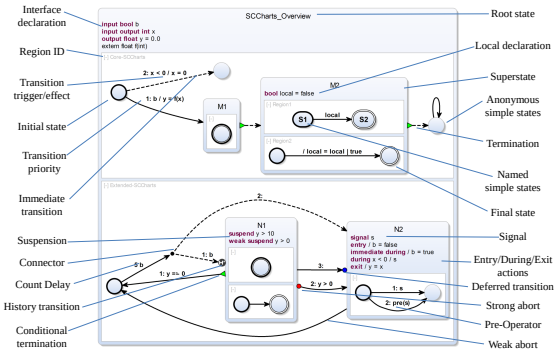

- **Observation I**: Numerous features
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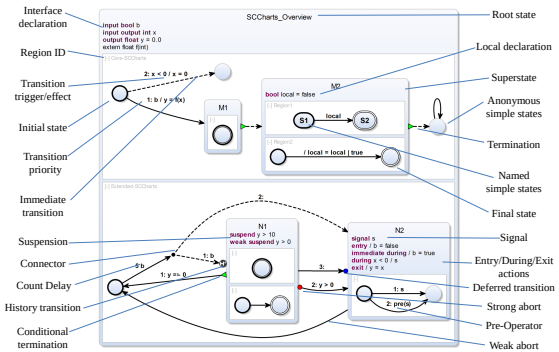

- **Observation I**: Numerous features
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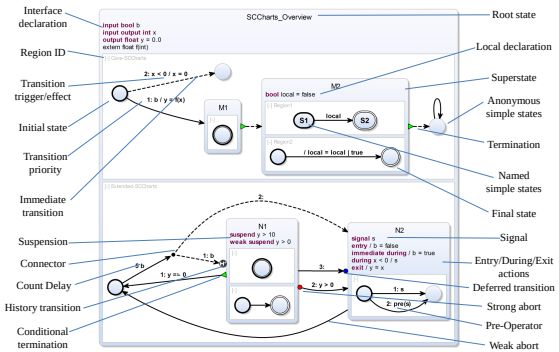
  - ☹ Direct compilation & verification more complex

Motivation for Core SCCharts



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- **Observation II**

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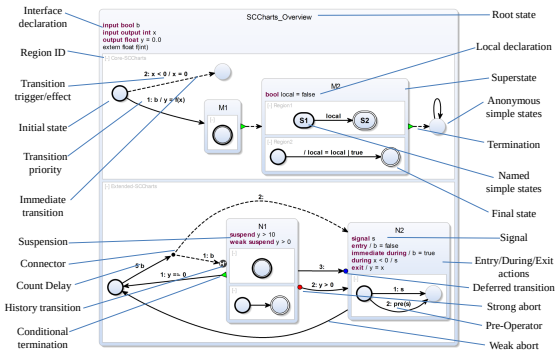

- **Observation I**: Numerous features
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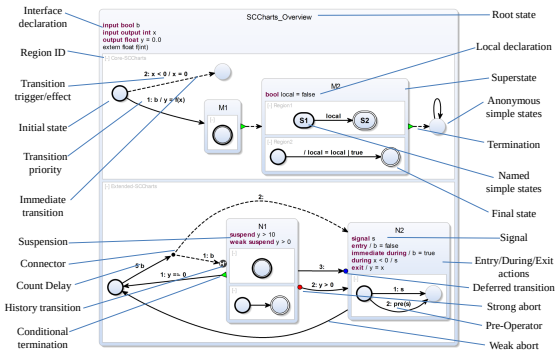
- **Observation II**: Various features can be expressed by other ones

Motivation for Core SCCharts



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- **Consequence**

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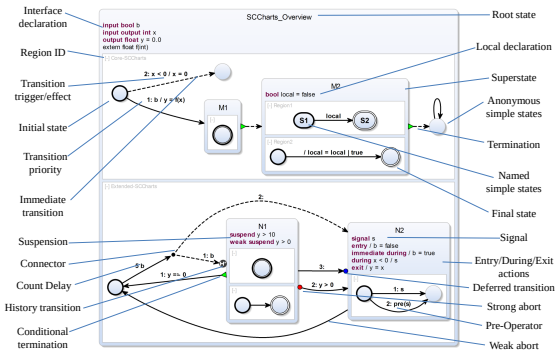

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  - ☺ Compactness / readability of models
  - ☹ Steeper learning curve
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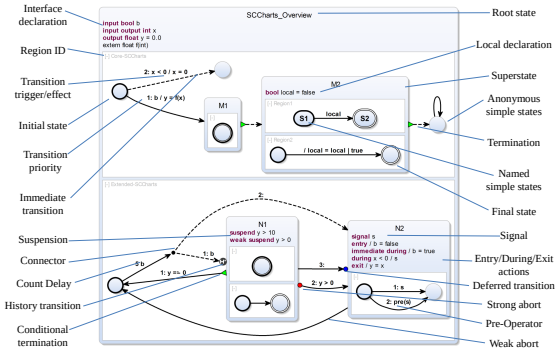
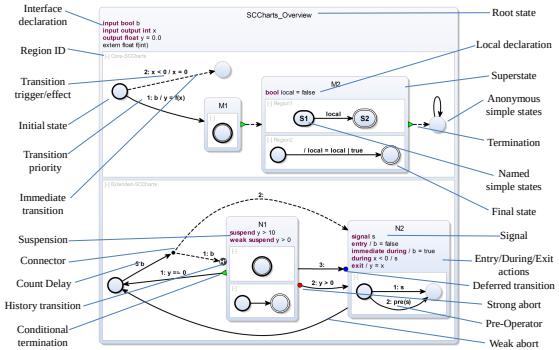
- **Observation II**: Various features can be expressed by other ones
- **Consequence**: ⇒ Define extended features by means of base features

Motivation (Cont'd)



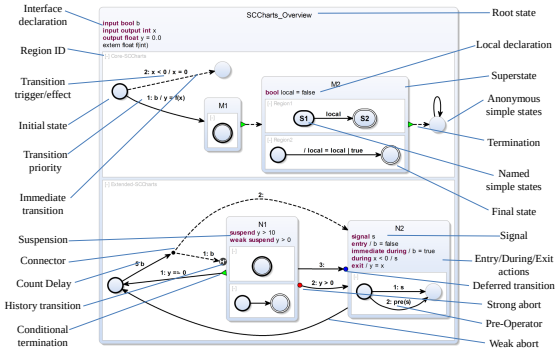
- **Advantages**

Motivation (Cont'd)



- **Advantages**:
  - Minimal base language (Core SCCharts)
    + advanced features (Extended SCCharts)

Motivation (Cont'd)



- **Advantages**:
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    - Similar to Esterel Kernel Statements & Statement Expansion

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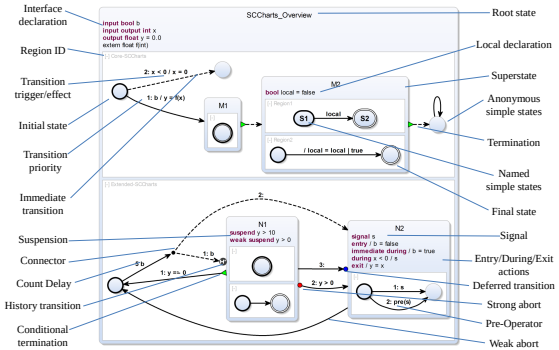

- **Advantages**:
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  - Advanced features are *syntactic sugar*

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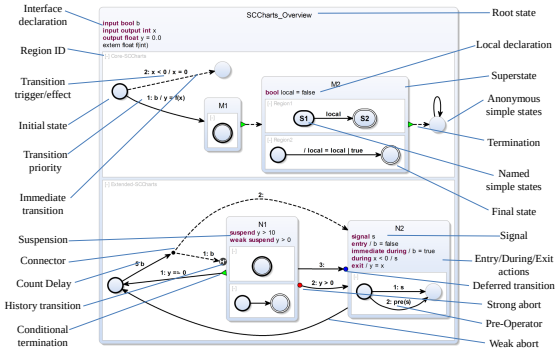

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  - Advanced features are *syntactic sugar*
  - Extensible

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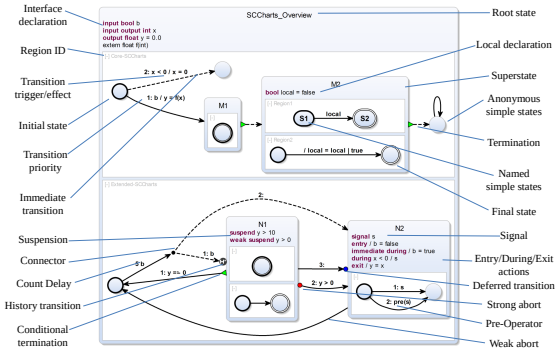
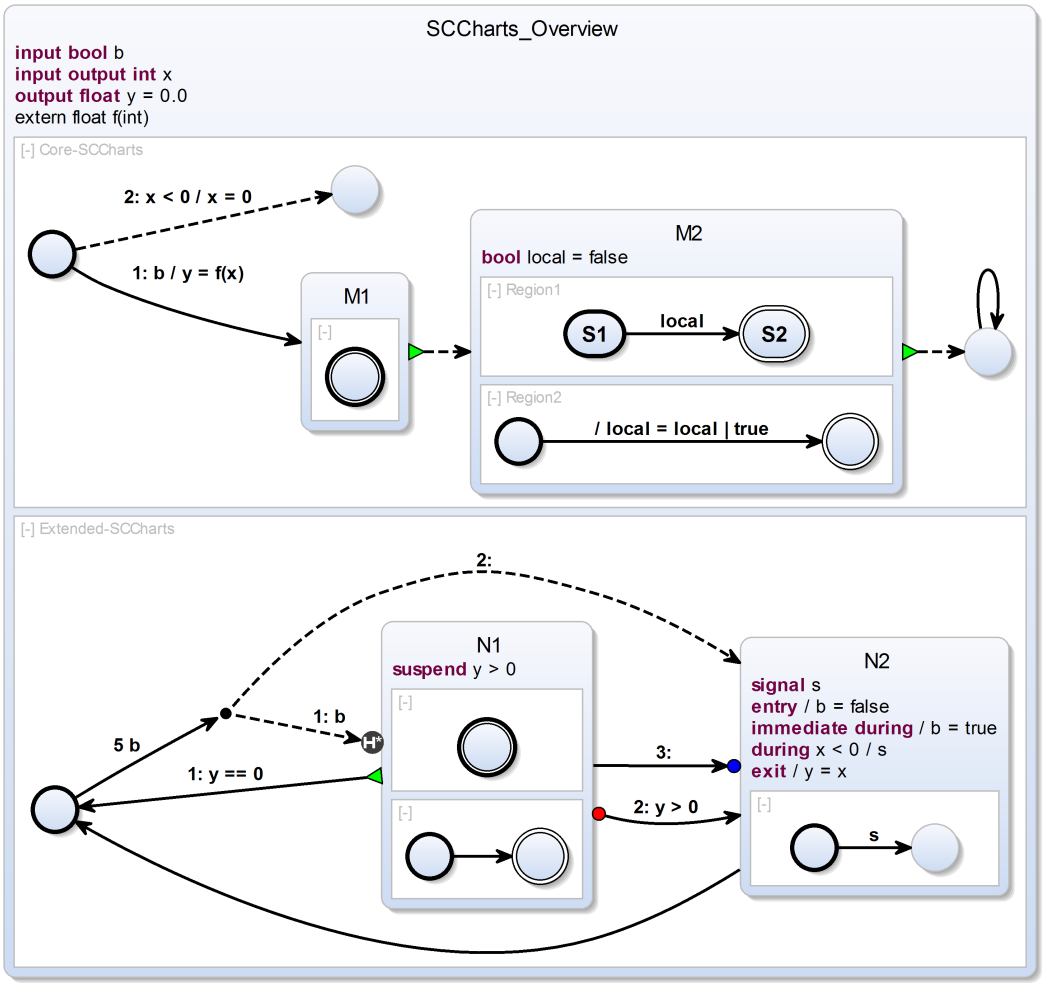


- **Advantages**:
  - Minimal base language (Core SCCharts)
    + advanced features (Extended SCCharts)
    - Similar to Esterel Kernel Statements & Statement Expansion
  - Advanced features are *syntactic sugar*
  - Extensible
  - Compilation (ongoing research)
    - Modular & extensible
    - Less complex
    - Possibly less efficient

SCCharts — Core & Extended Features



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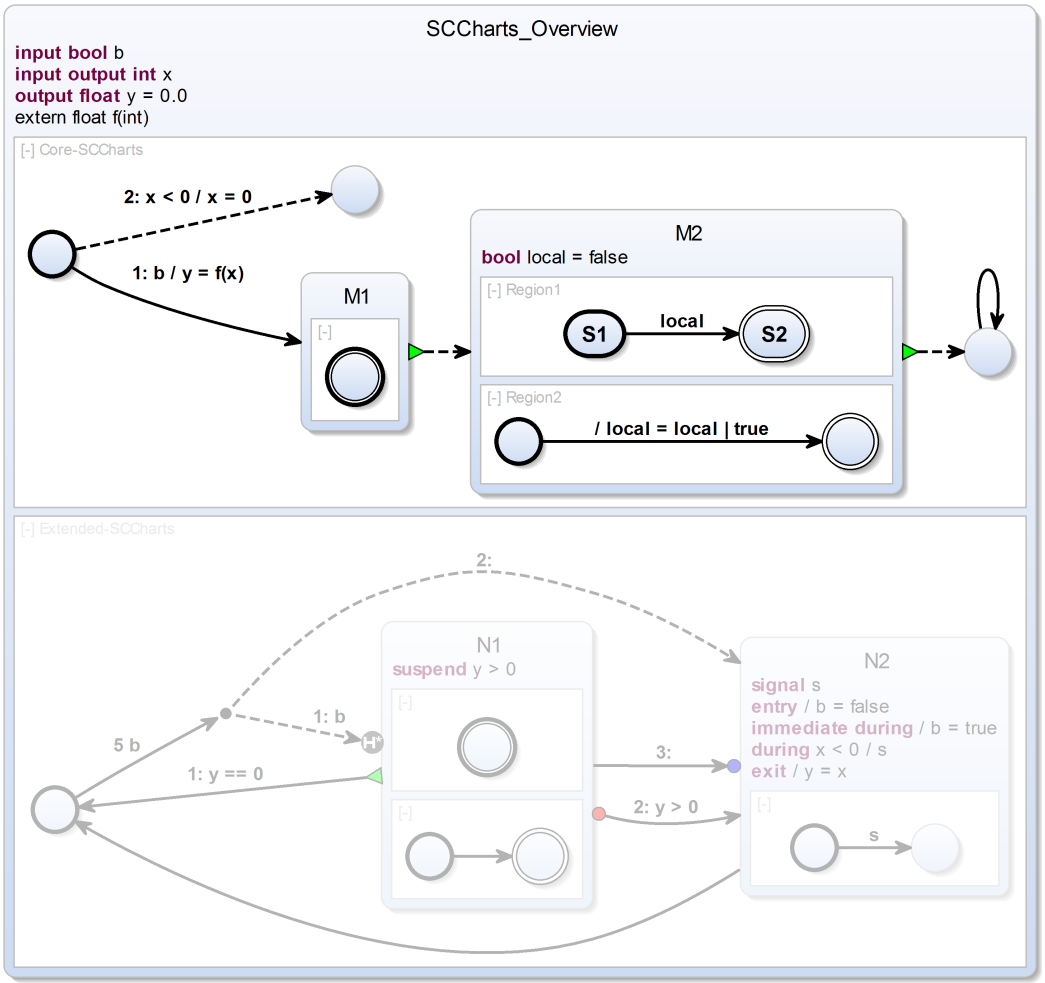

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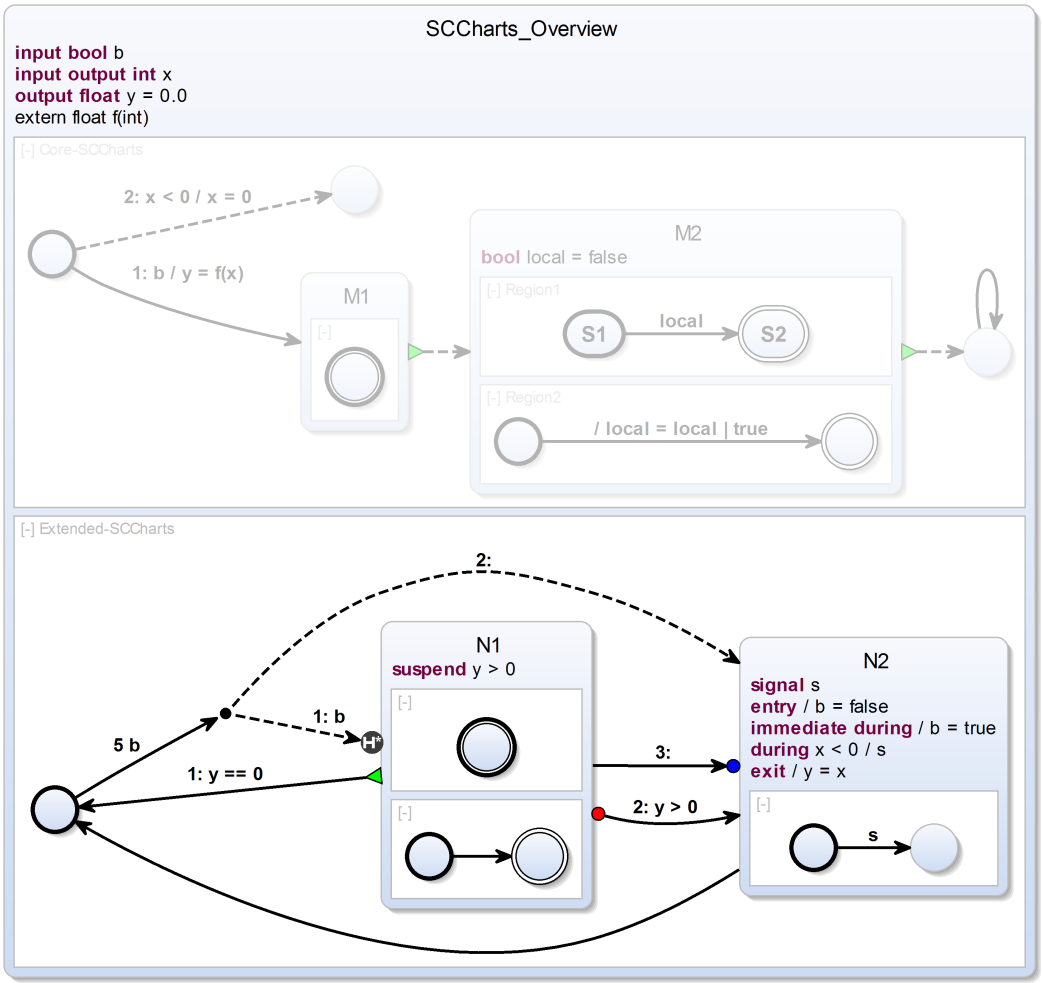

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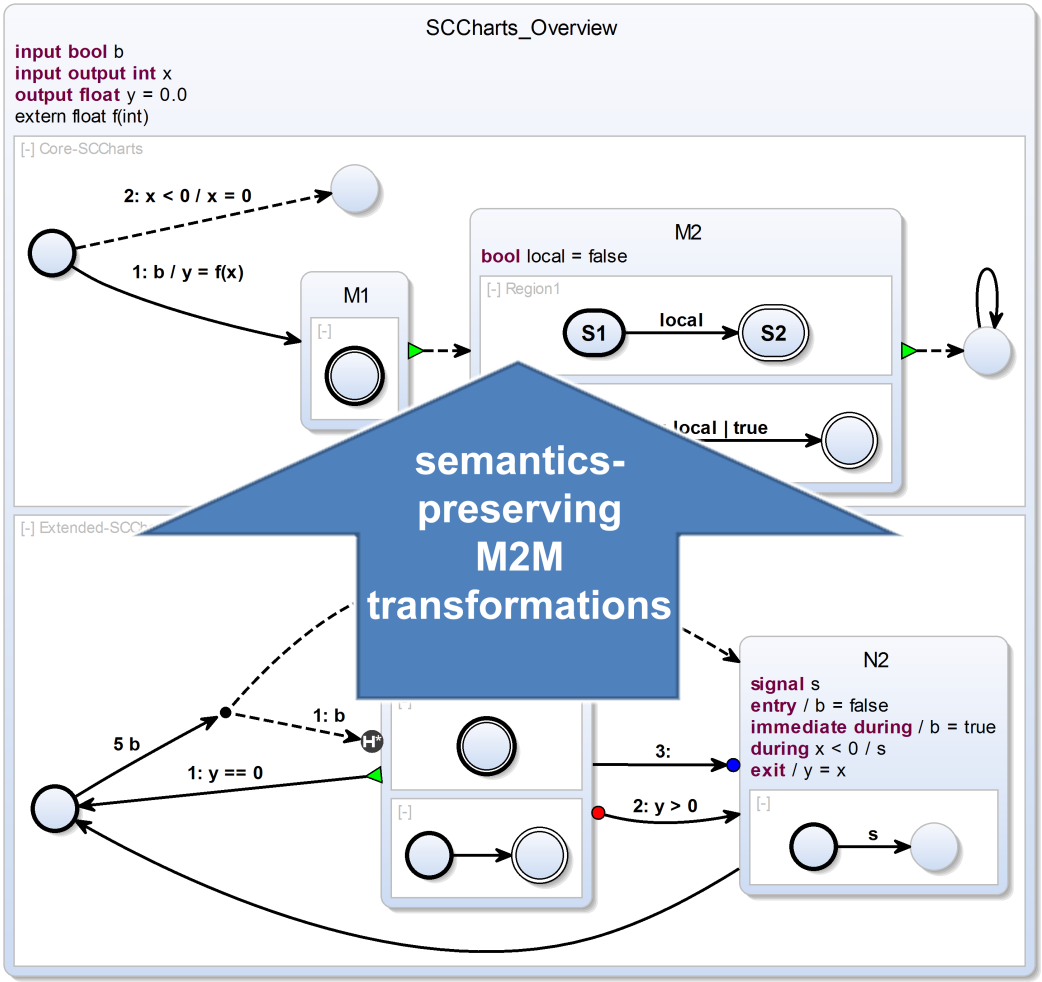
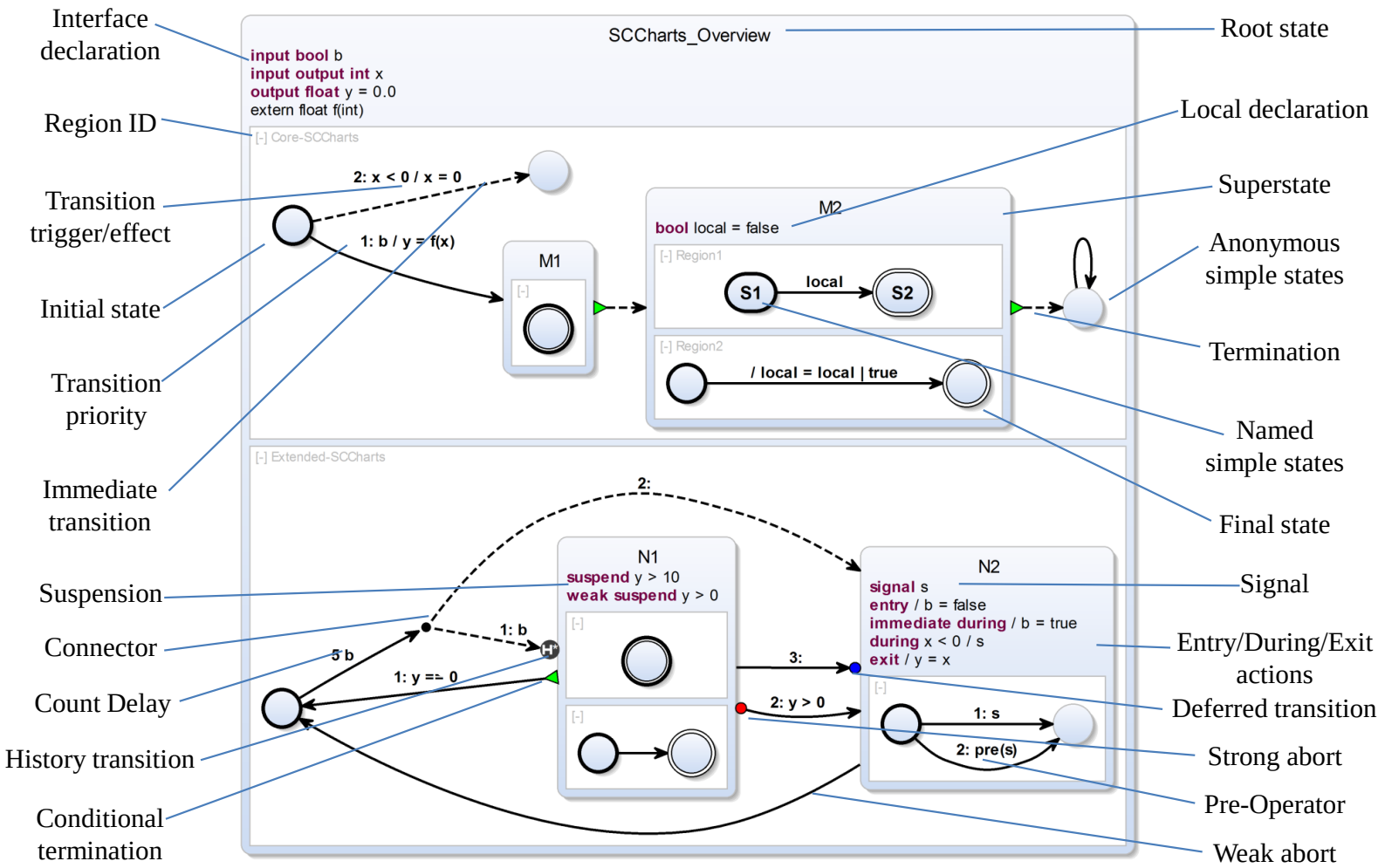


Overview

- SCCharts Overview
- Extended SCCharts → Core SCCharts
- Normalizing Core SCCharts
- Implementation in KIELER

SCCharts — Core Transformations Examples



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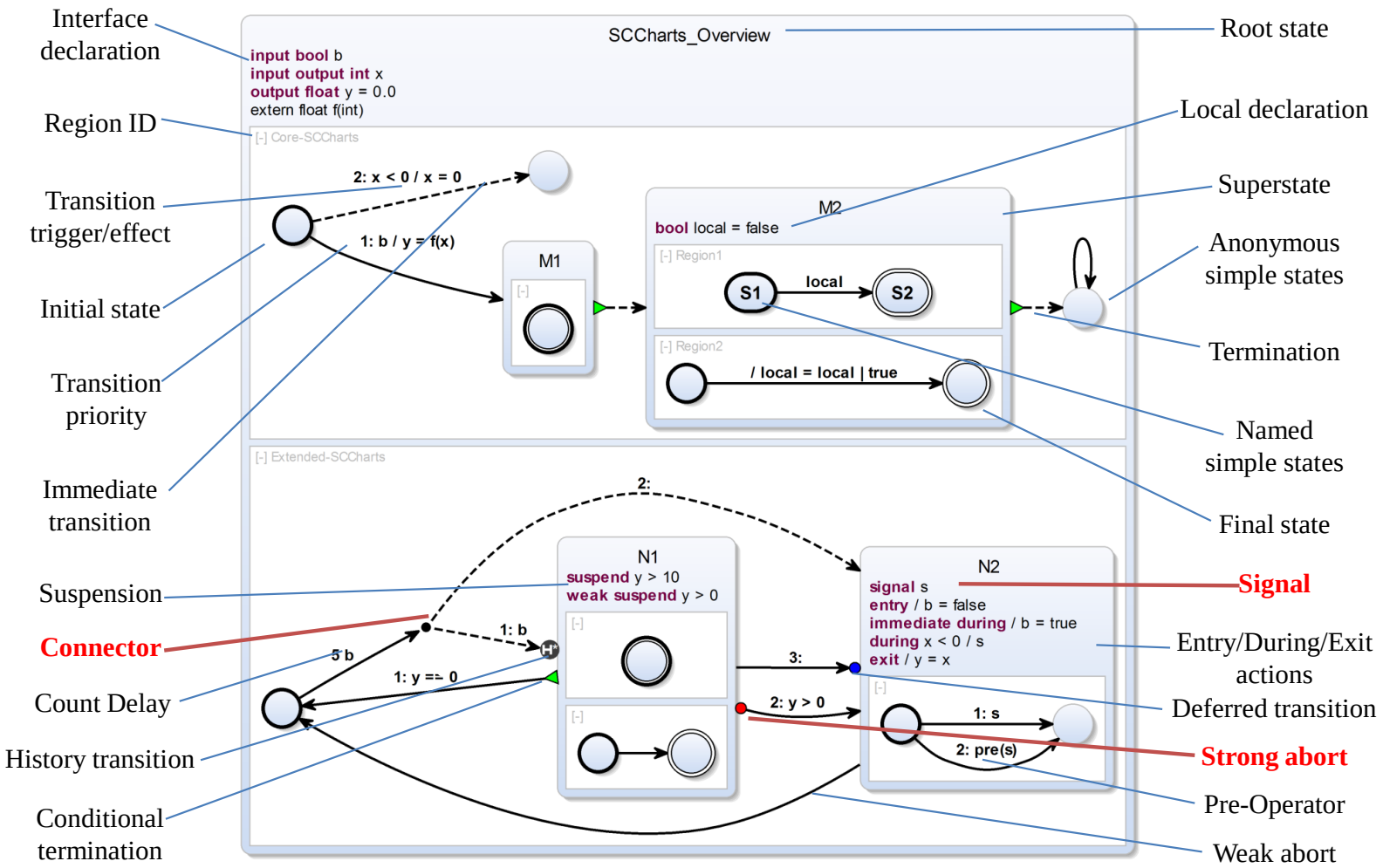
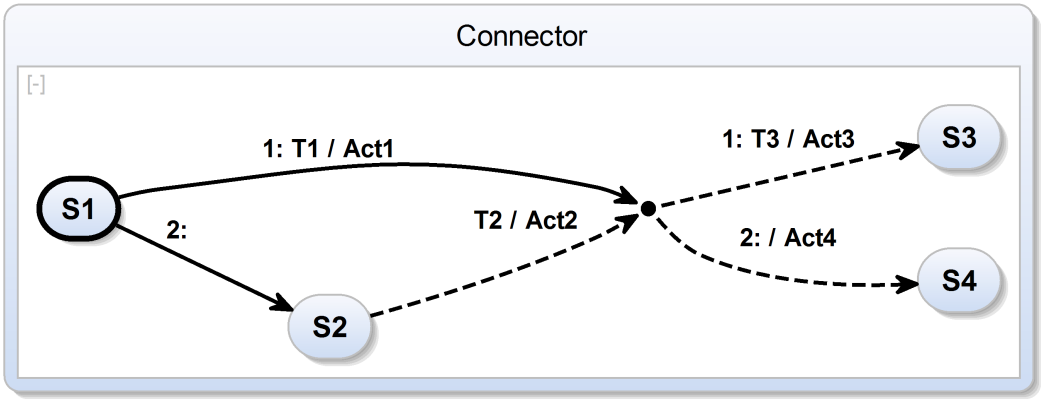


Transforming Connectors



Extended SCCharts with Connectors

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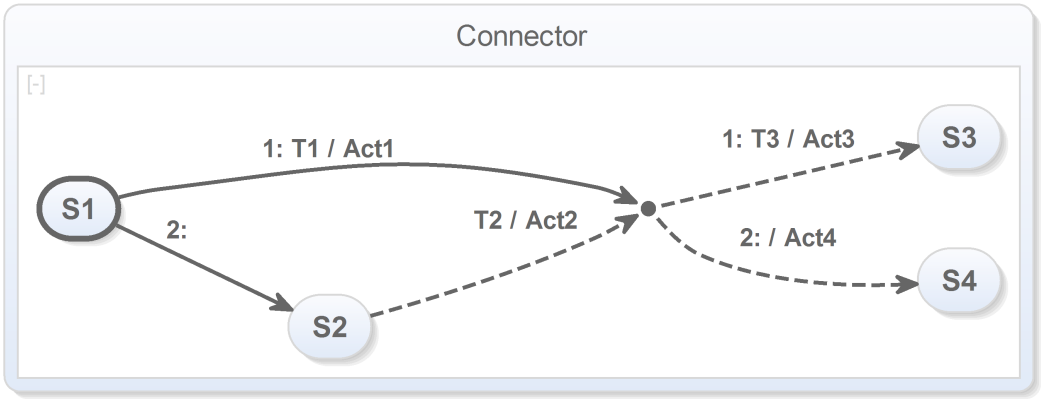

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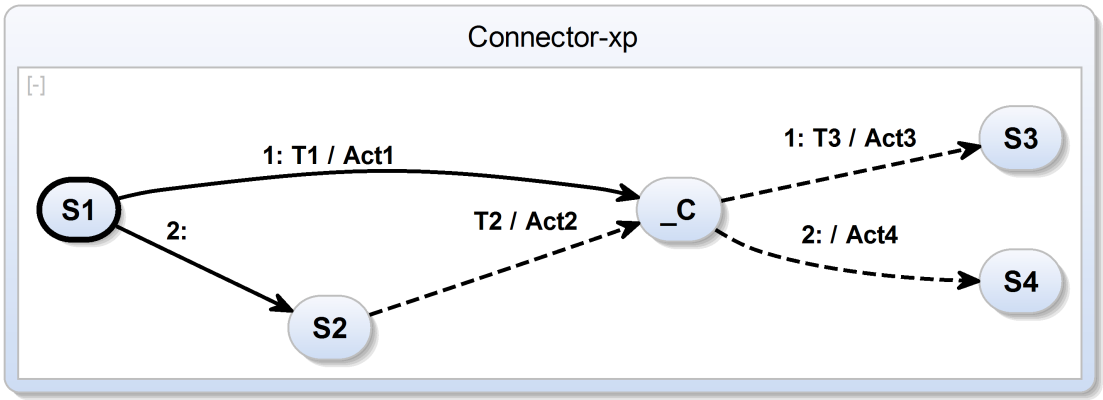
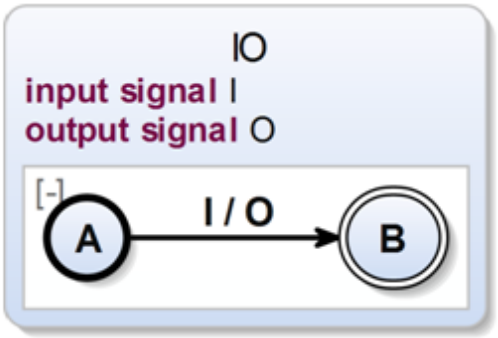


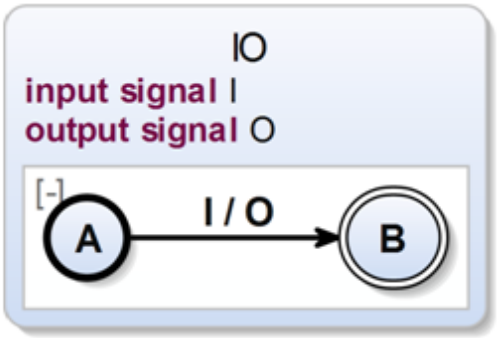
Core SCCharts without Connectors

Transforming Signals



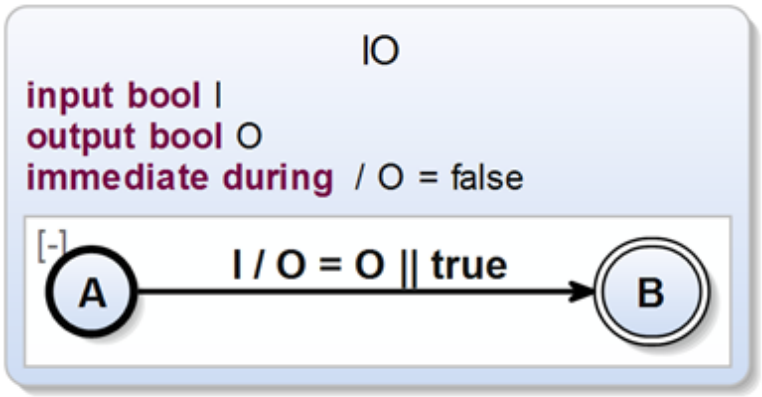
Extended SCCharts with Signals

Transforming Signals



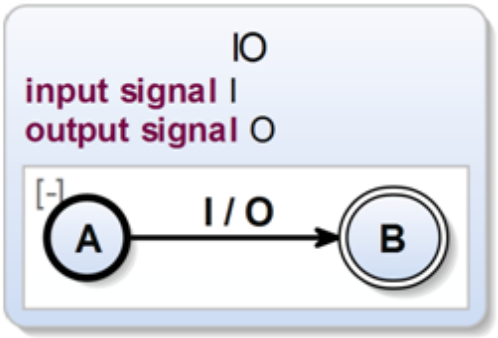
Extended SCCharts with Signals

Signal expansion



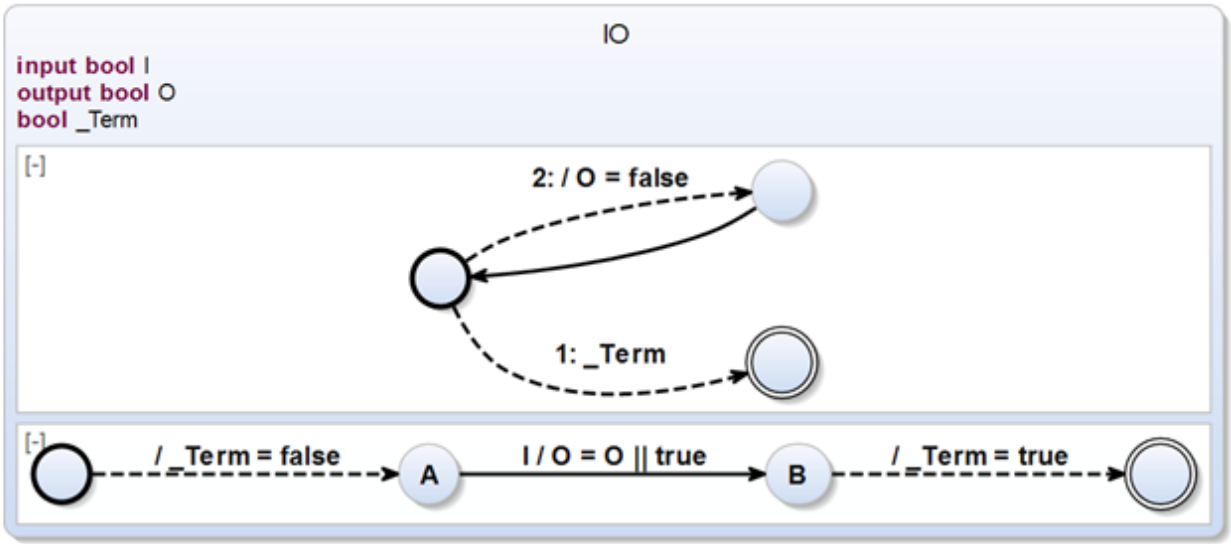
Core SCCharts with During Actions

Transforming Signals



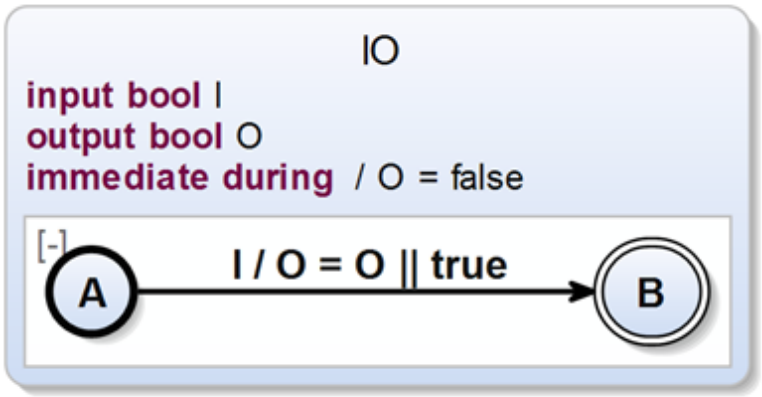
Extended SCCharts with Signals

Signal expansion



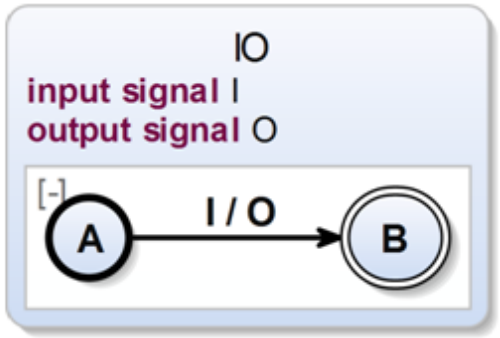
Core SCCharts only

Action expansion



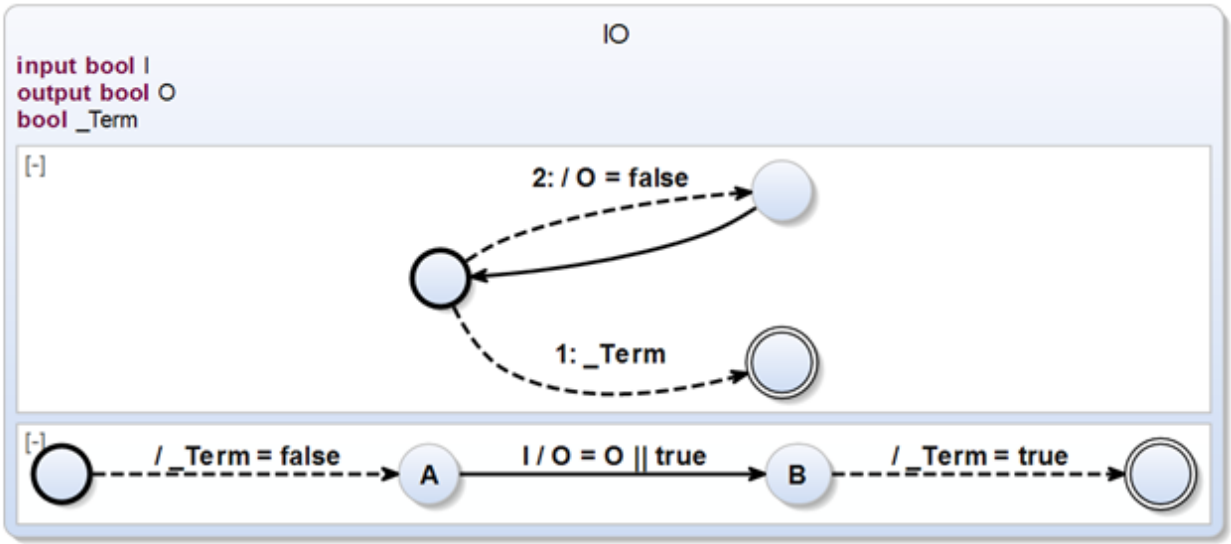
Core SCCharts with During Actions

Transforming Signals



Extended SCCharts with Signals

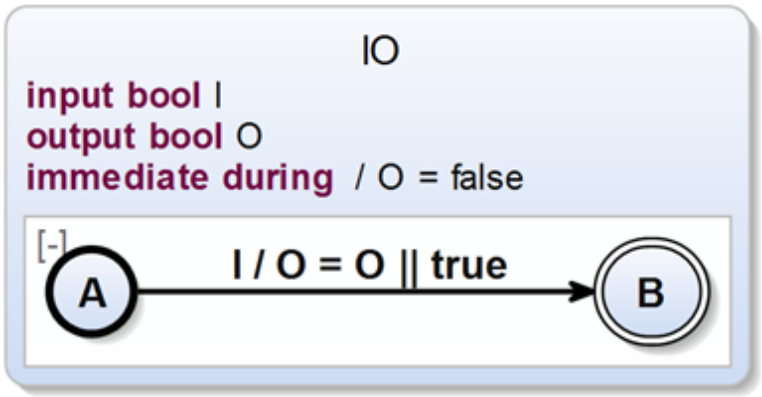
Signal expansion



Core SCCharts only

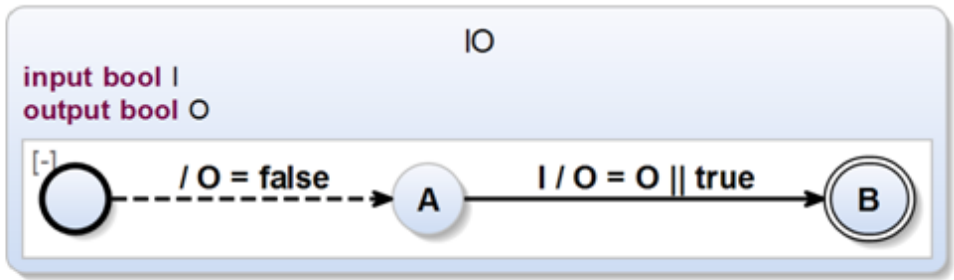
Optimization

Action expansion



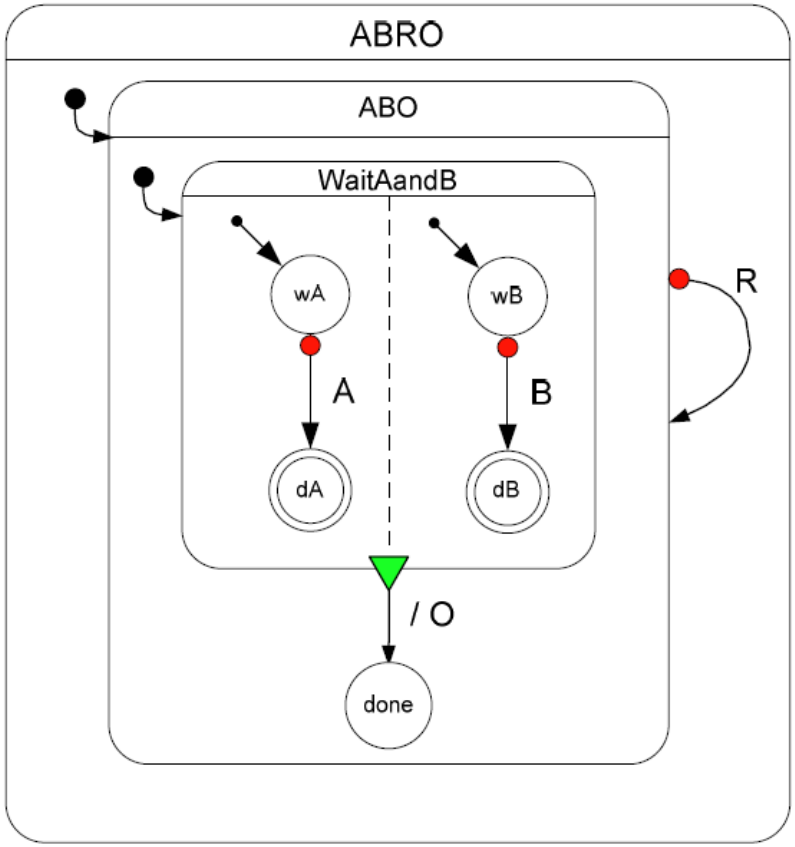
Core SCCharts with During Actions

Action expansion (alternative)



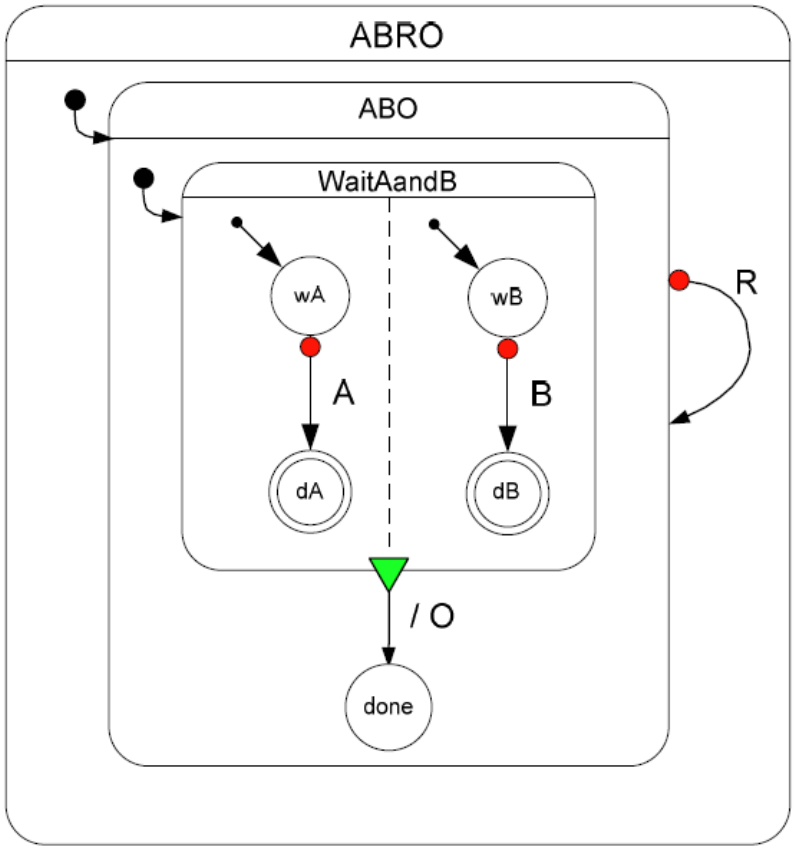
Core SCCharts only (optimized)

SyncChart and SCChart ABRO

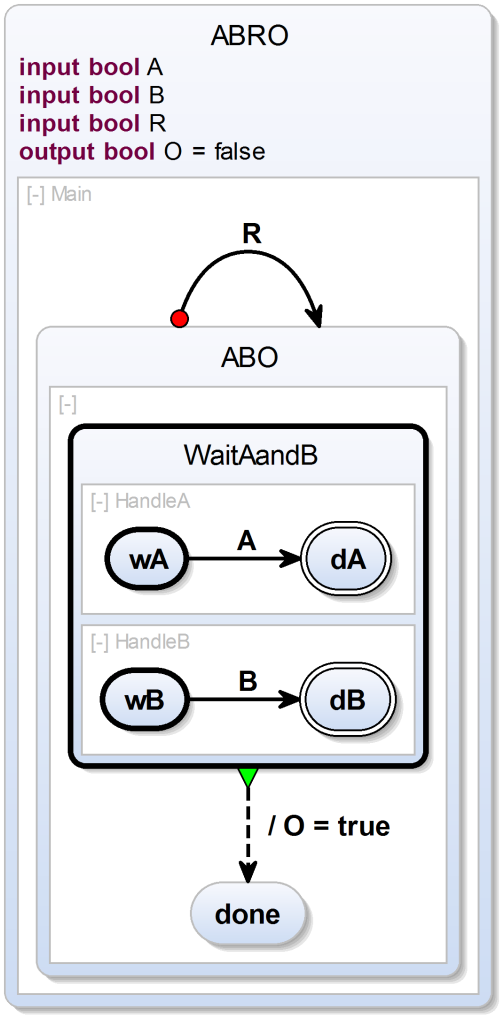


[Charles André, Semantics of SyncCharts, 2003]

SyncChart and SCChart ABRO

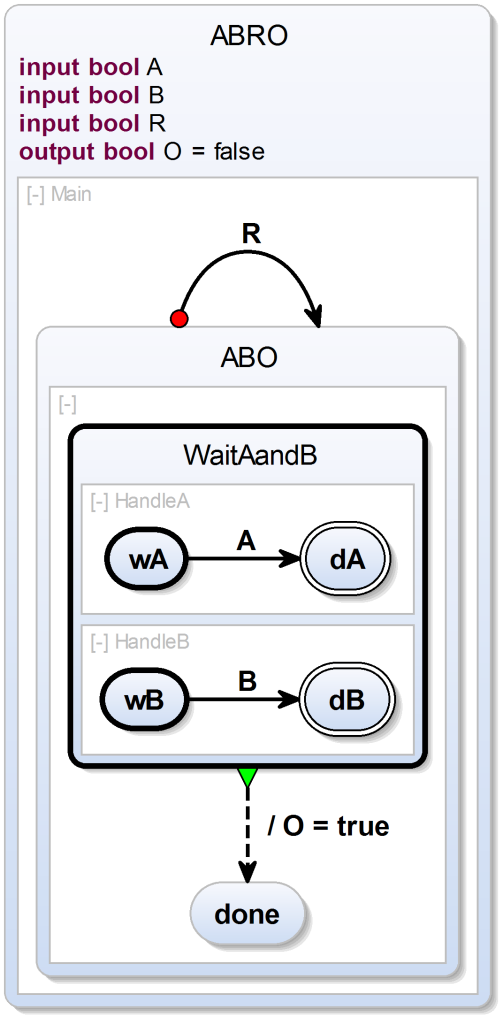


[Charles André, Semantics of SyncCharts, 2003]



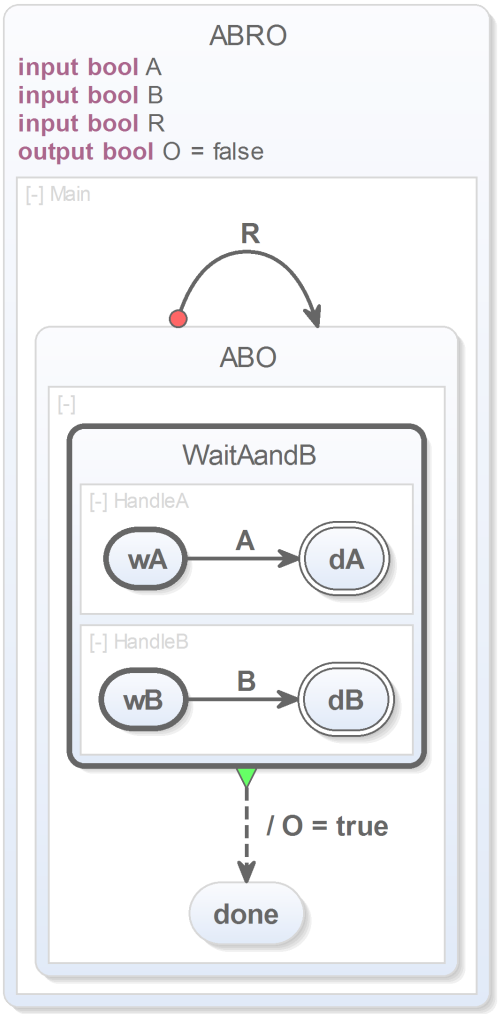
. ABRO SCChart

ABRO — Transforming Strong Aborts

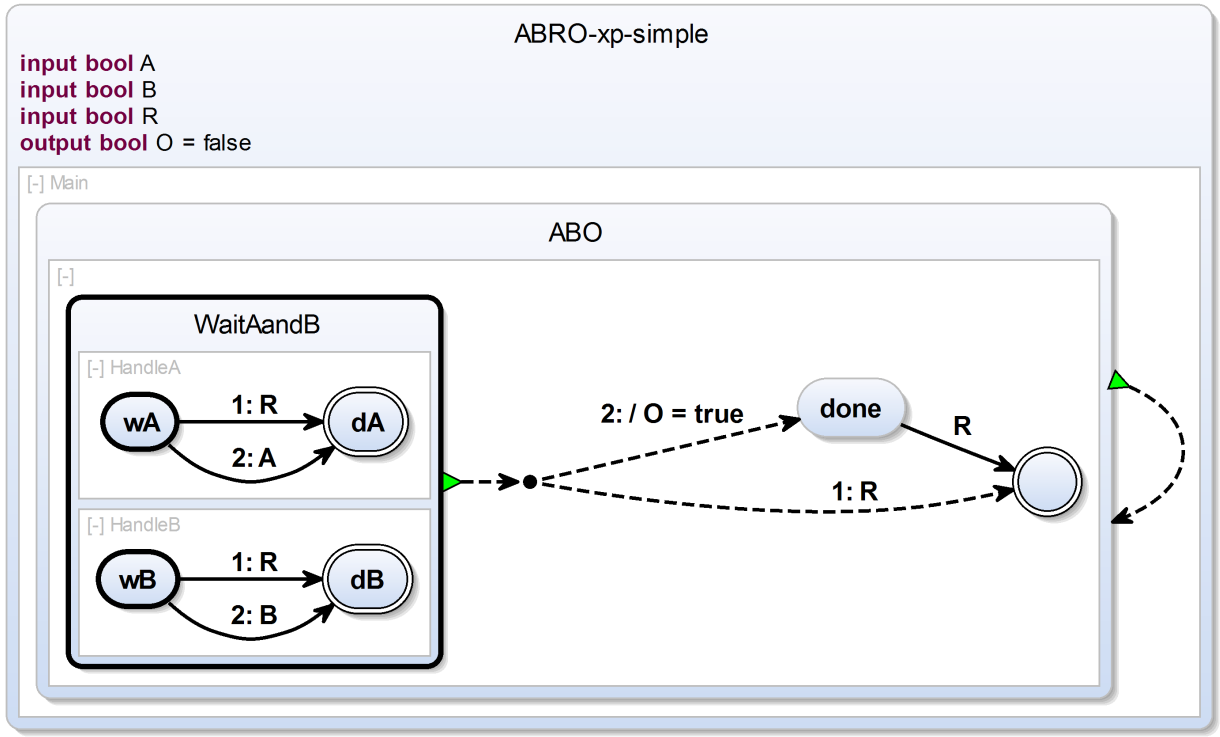


ABRO SCChart with Strong Abort

ABRO — Transforming Strong Aborts

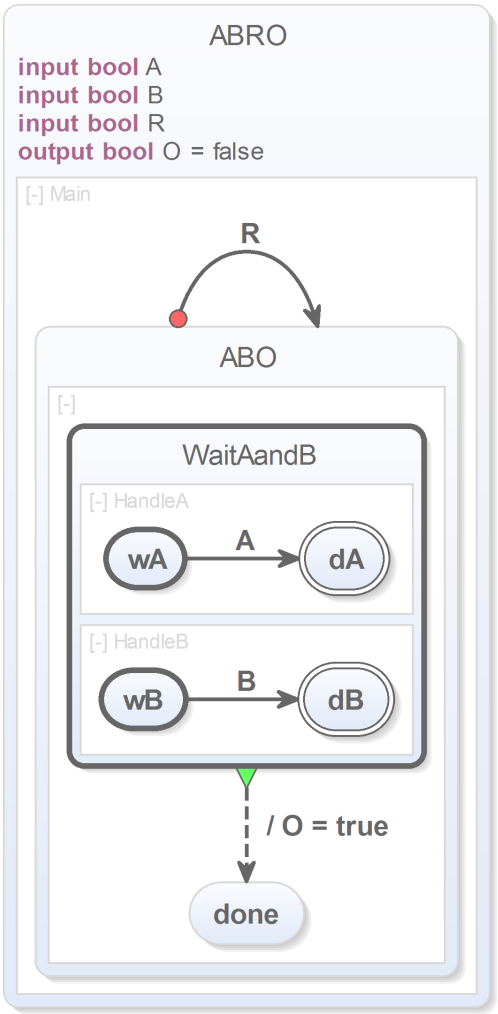


ABRO SCChart with Strong Abort

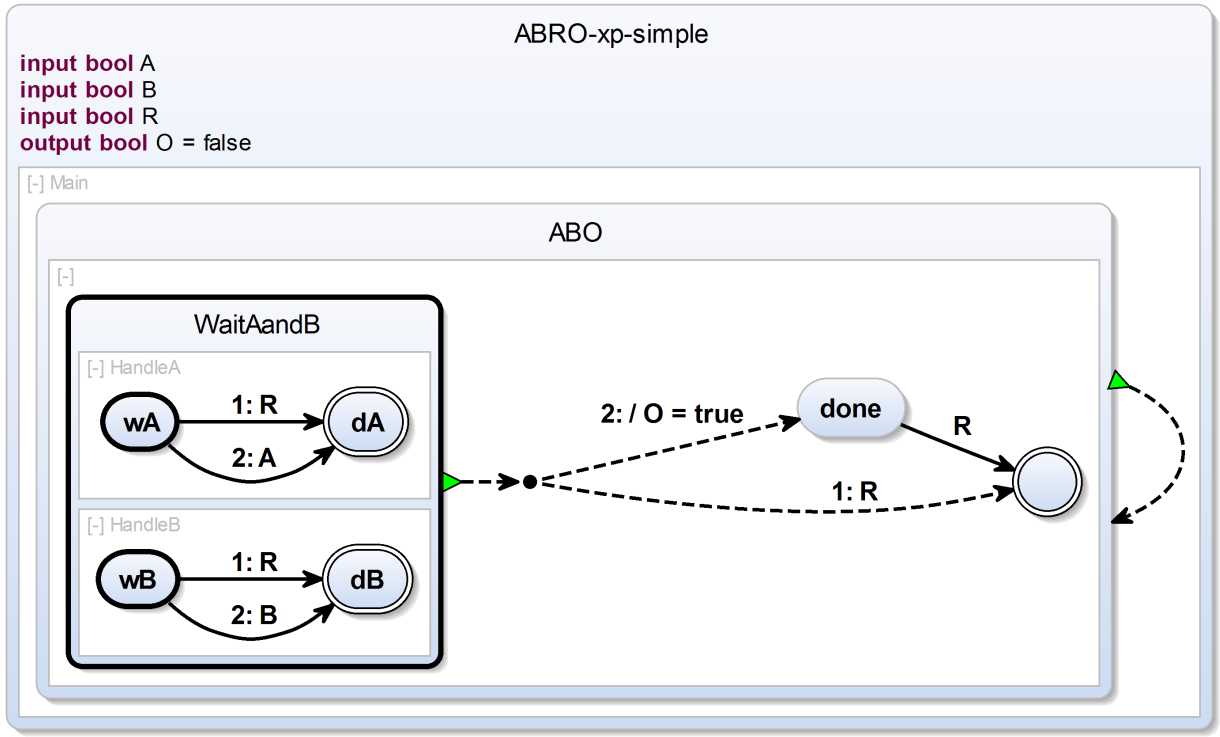


Core SCChart without Strong Abort

ABRO — Transforming Strong Aborts



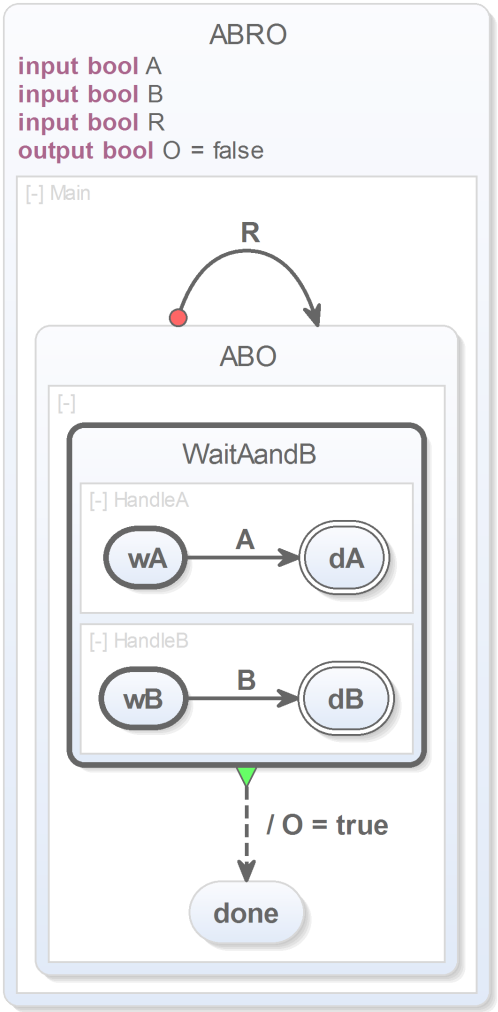
ABRO SCChart with Strong Abort



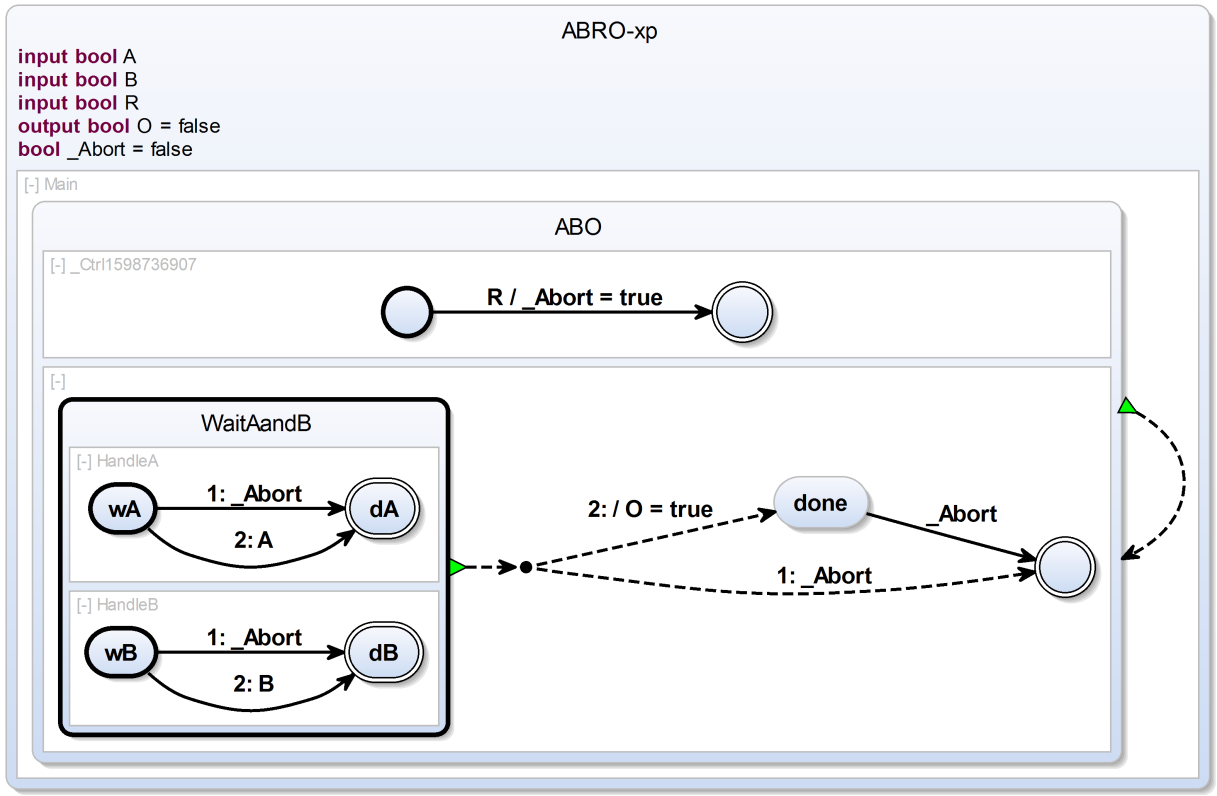
Core SCChart without Strong Abort

→ **Write-Things-Once (WTO) principle violated**

ABRO — Transforming Strong Aborts (cont'd)

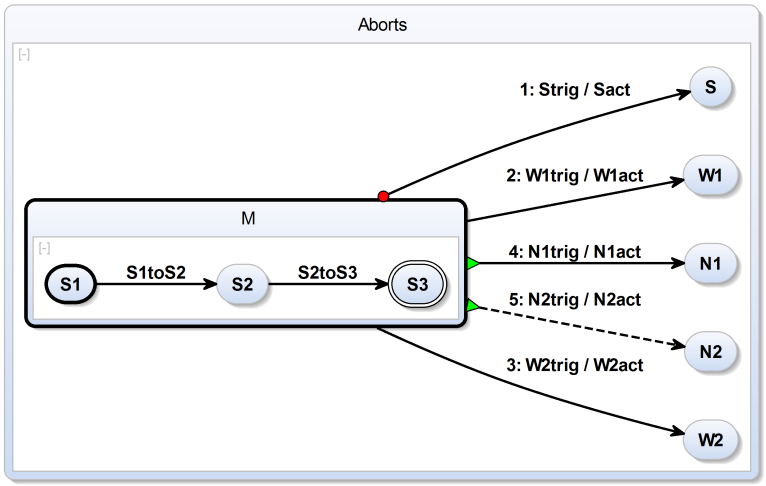


ABRO SCChart with Strong Abort



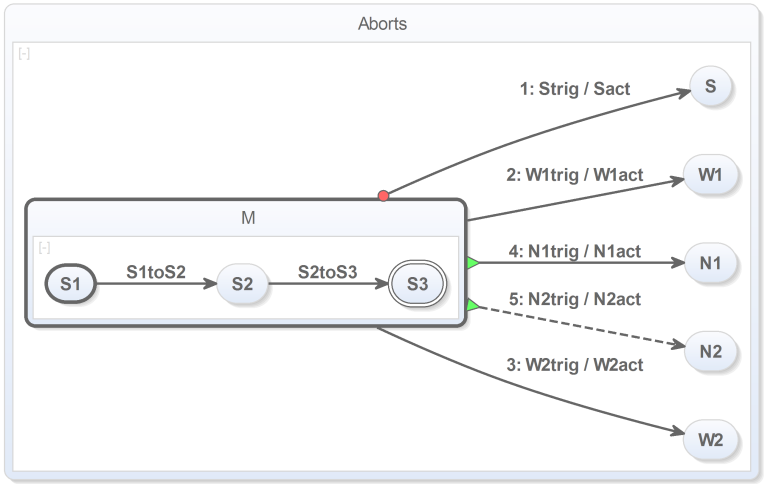
Core SCChart without Strong Abort and WTO

Transforming General Aborts

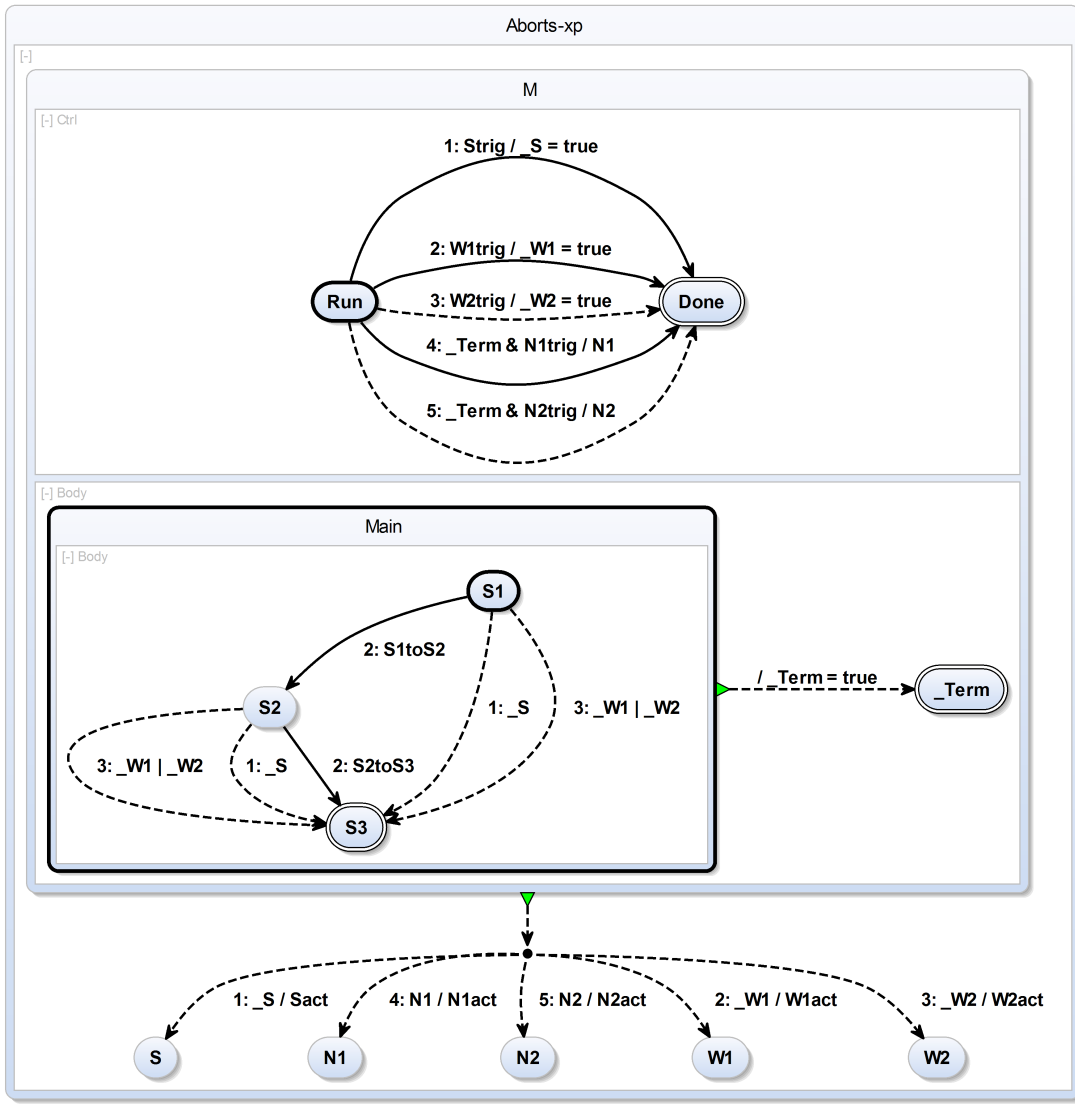


Extended SCCharts with Aborts

Transforming General Aborts



Extended SCCharts with Aborts

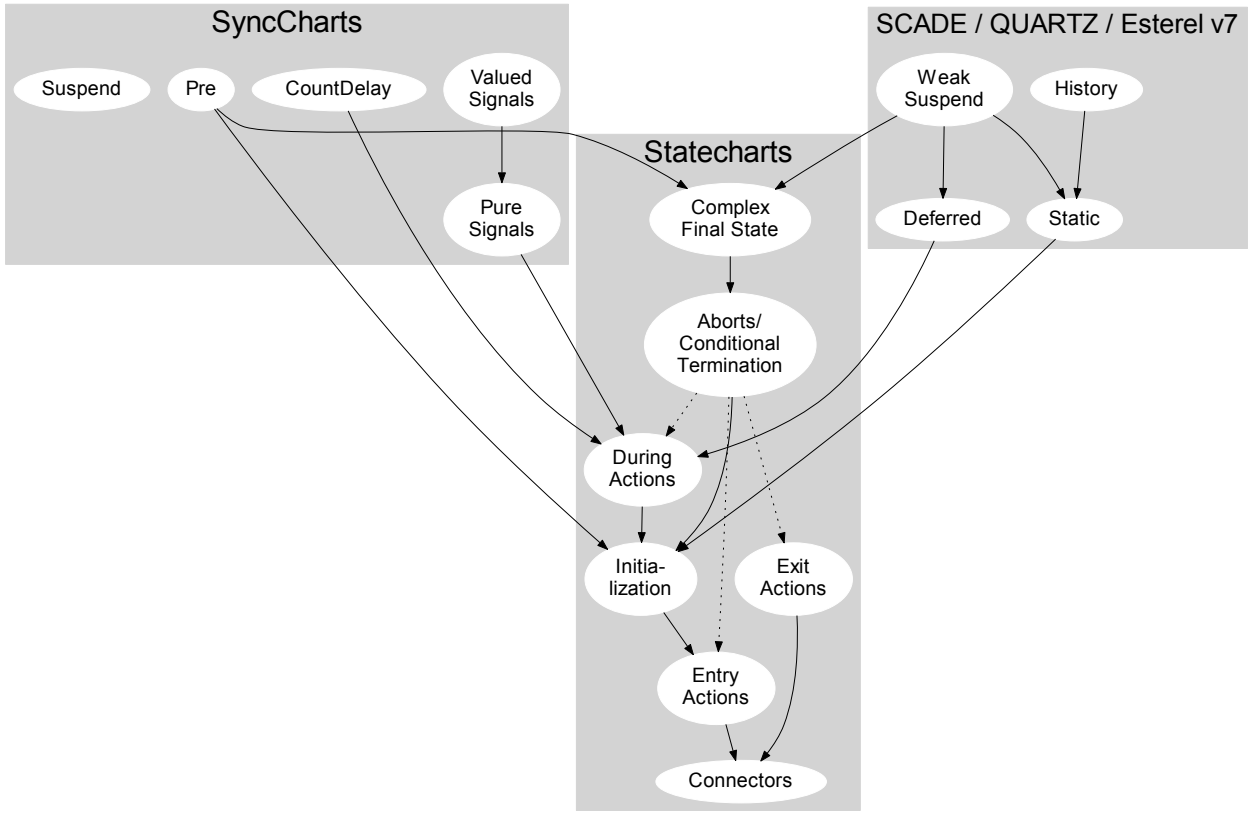


Core SCCharts with one Termination

Overview

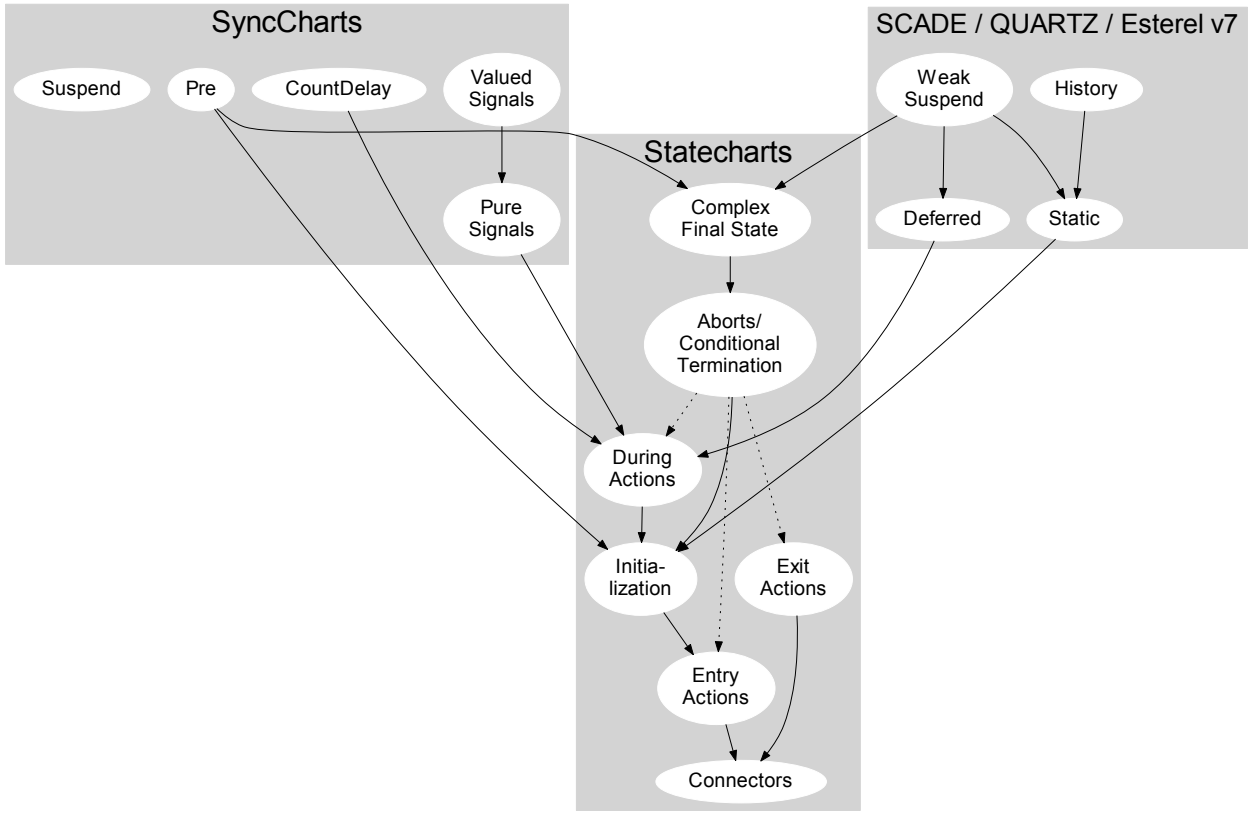
- SCCharts Overview
- Extended SCCharts → Core SCCharts
- Normalizing Core SCCharts
- Implementation in KIELER

Single-Pass Language-Driven Incremental Compilation (SLIC)



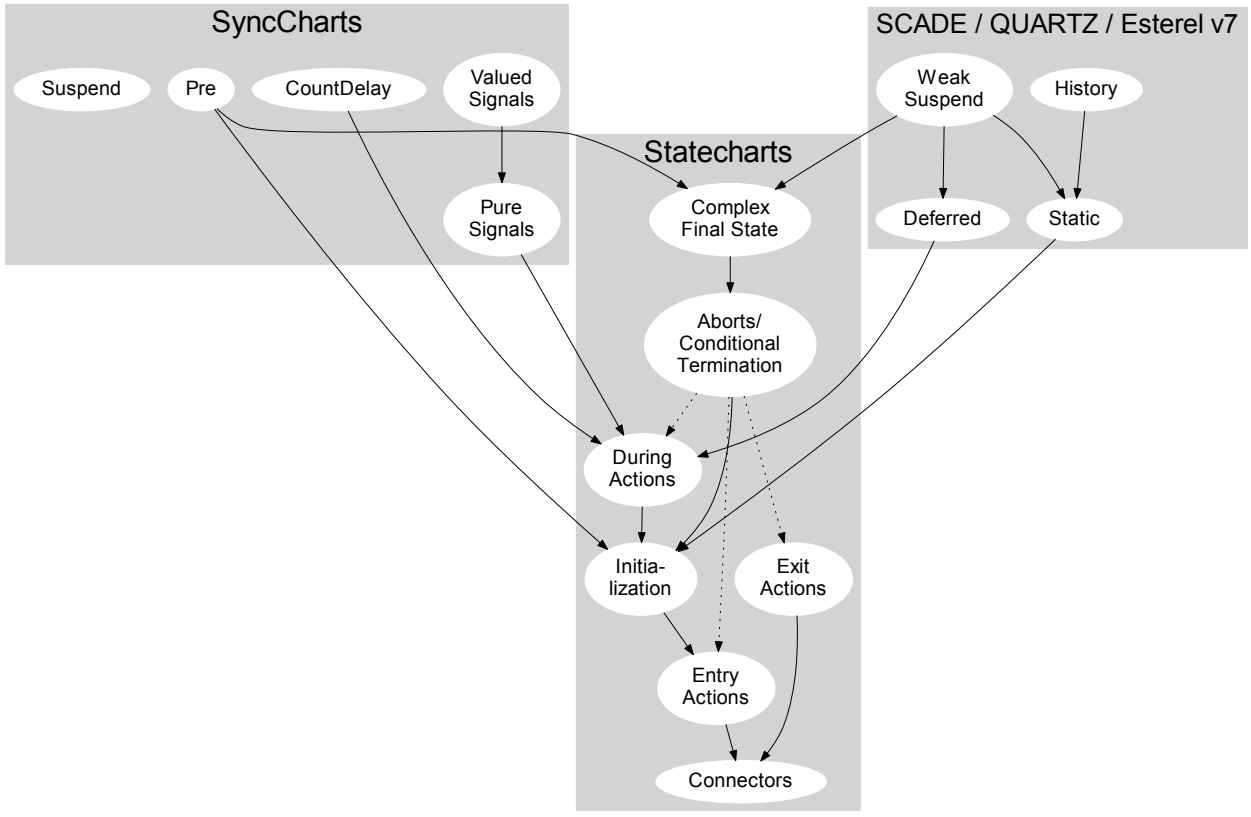
- Some core transformations will produce (use) some other extended features (solid lines)

Single-Pass Language-Driven Incremental Compilation (SLIC)



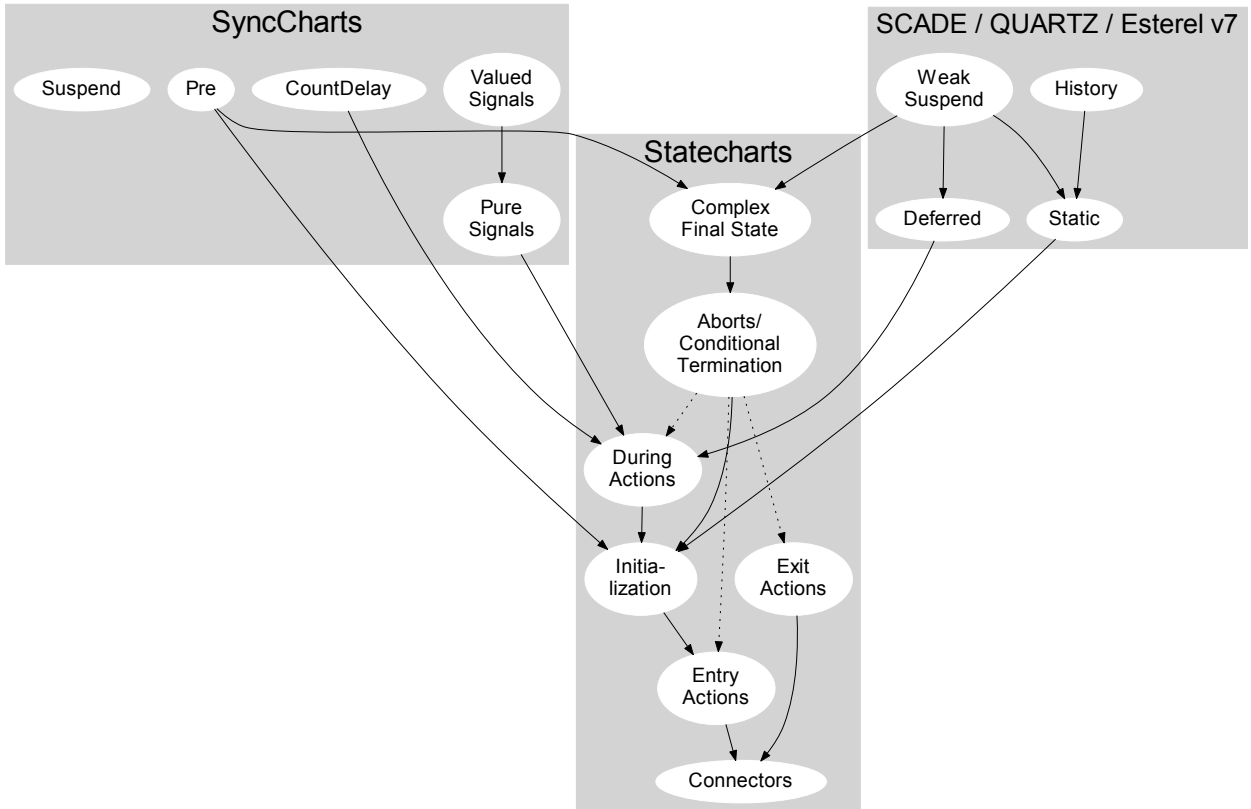
- Some core transformations will produce (use) some other extended features (solid lines)
- Other core transformations cannot handle some extended features (dashed lines)

Single-Pass Language-Driven Incremental Compilation (SLIC)



- Some core transformations will produce (use) some other extended features (solid lines)
- Other core transformations cannot handle some extended features (dashed lines)
- $\rightarrow$ Order in which core transformations are applied is important

Single-Pass Language-Driven Incremental Compilation (SLIC)



- Some core transformations will produce (use) some other extended features (solid lines)
- Other core transformations cannot handle some extended features (dashed lines)
- $\rightarrow$ Order in which core transformations are applied is important
- $\rightarrow$ Dependencies (do not have any cycle, which would be forbidden)

Normalization

- Further simplify compilation process for Core SCCharts

Normalization

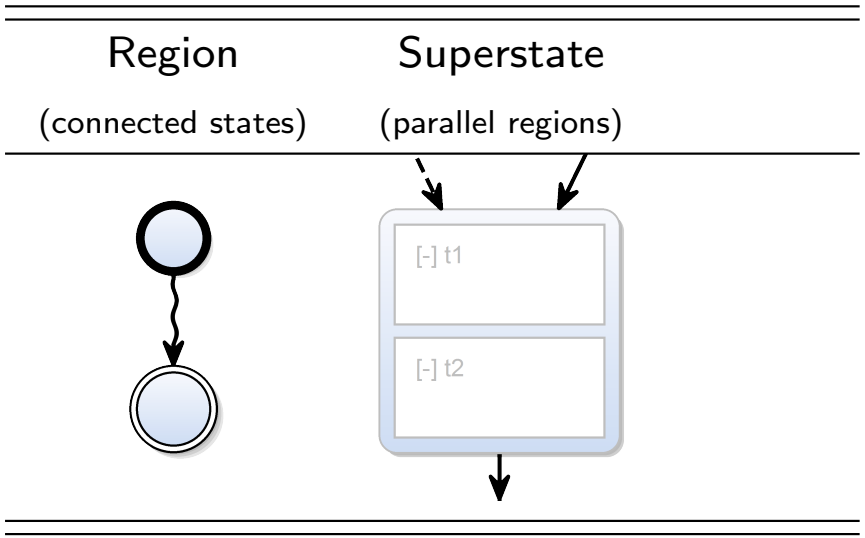
- Further simplify compilation process for Core SCCharts
- Allowed patterns:

Region

(connected states)

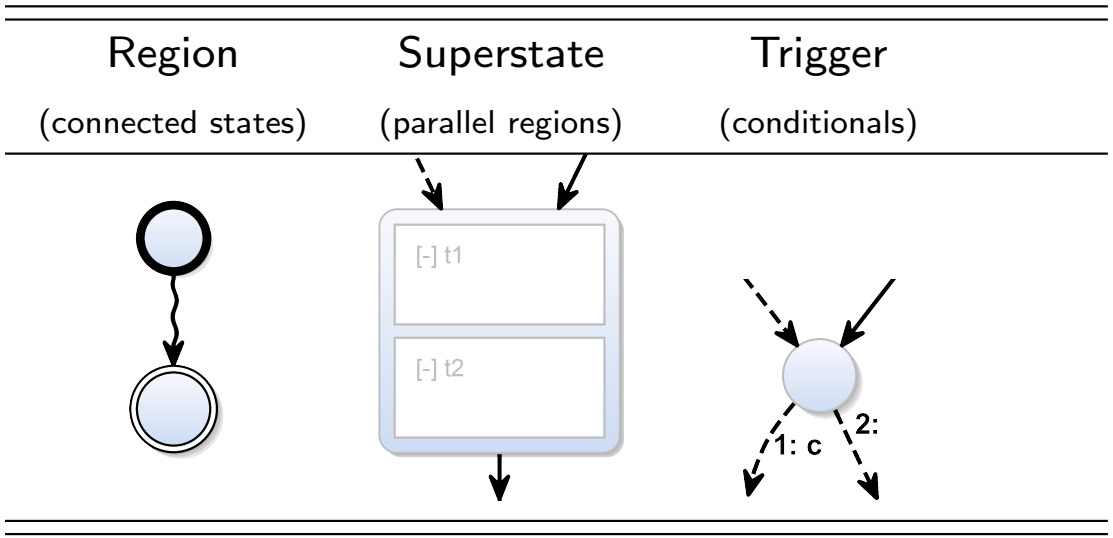
Normalization

- Further simplify compilation process for Core SCCharts
- Allowed patterns:



Normalization

- Further simplify compilation process for Core SCCharts
- Allowed patterns:



Normalization

- Further simplify compilation process for Core SCCharts
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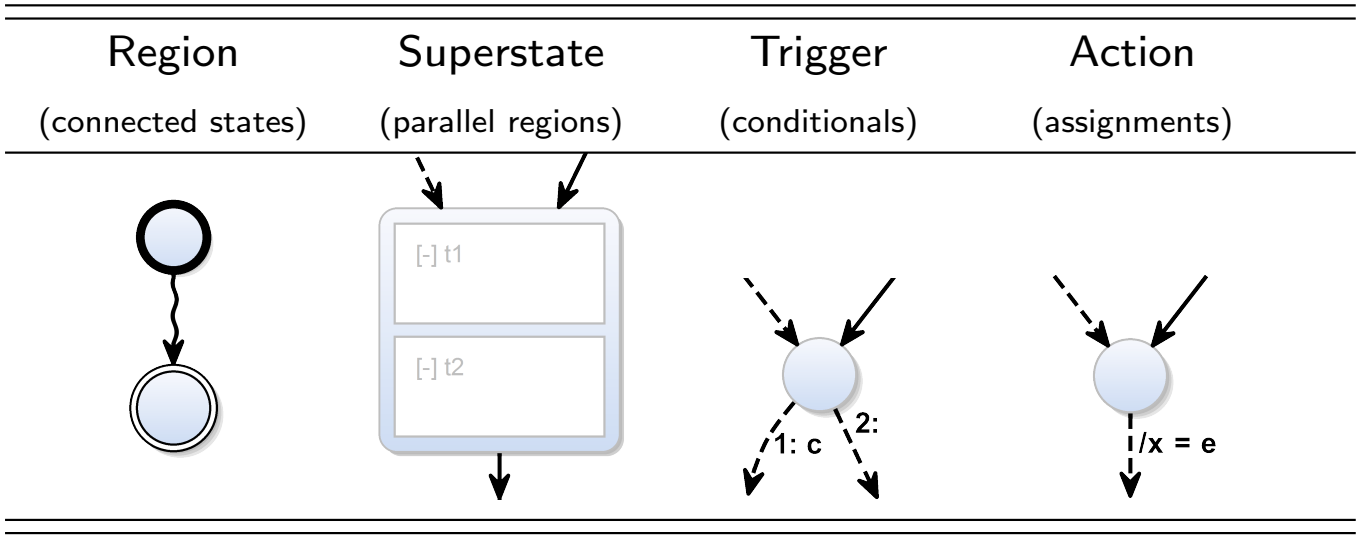
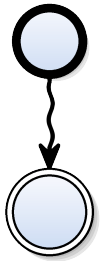
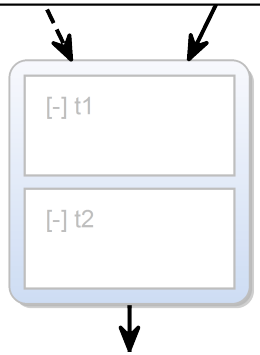
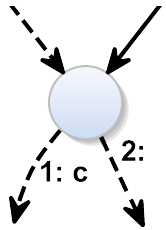
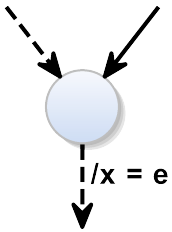
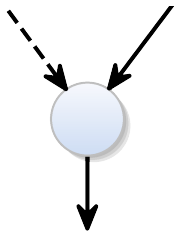
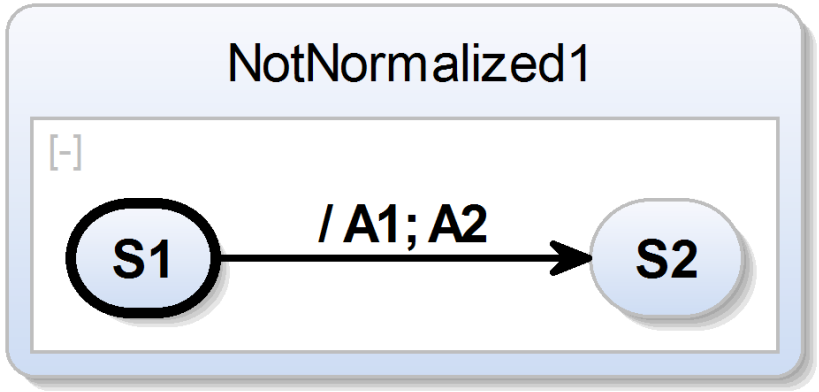


Normalization

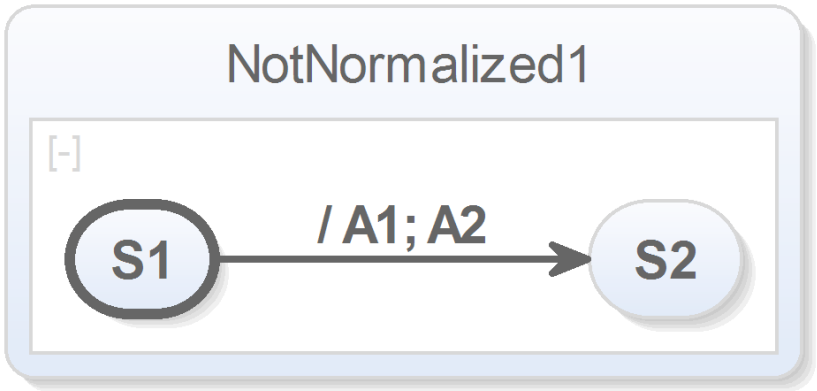
- Further simplify compilation process for Core SCCharts
- Allowed patterns:

Region	Superstate	Trigger	Action	State
(connected states)	(parallel regions)	(conditionals)	(assignments)	(tick boundary)
				

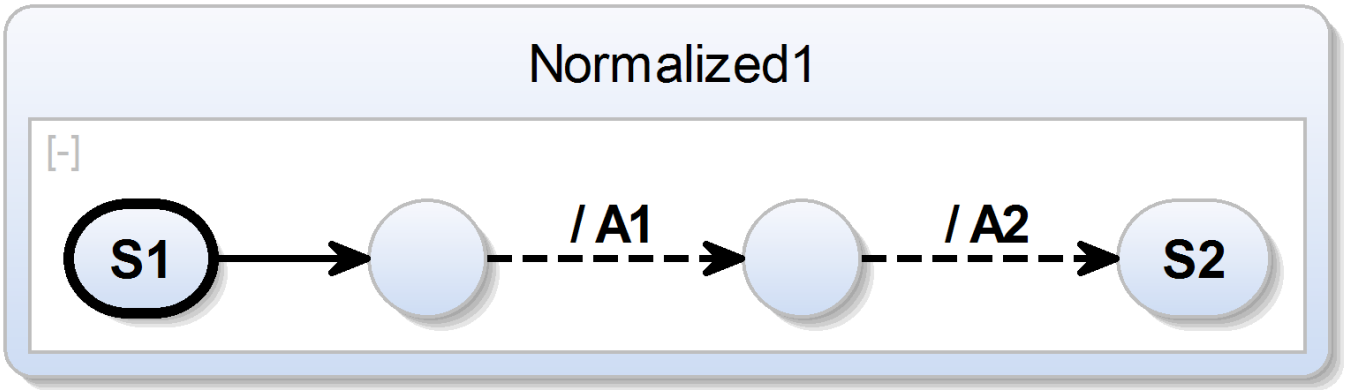
Actions Normalization



Actions Normalization

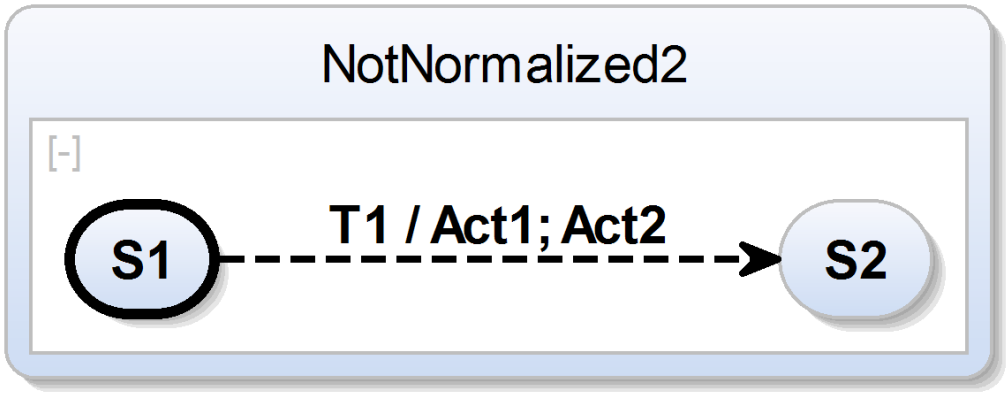


Core SCChart before normalization

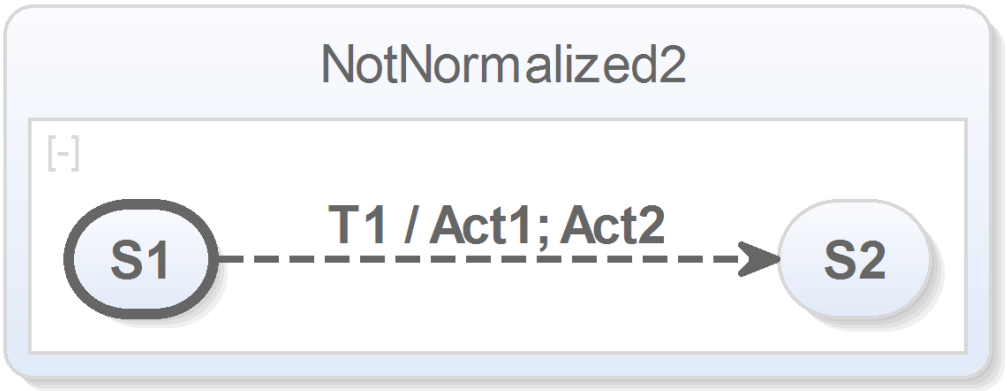


Core SCChart after normalization

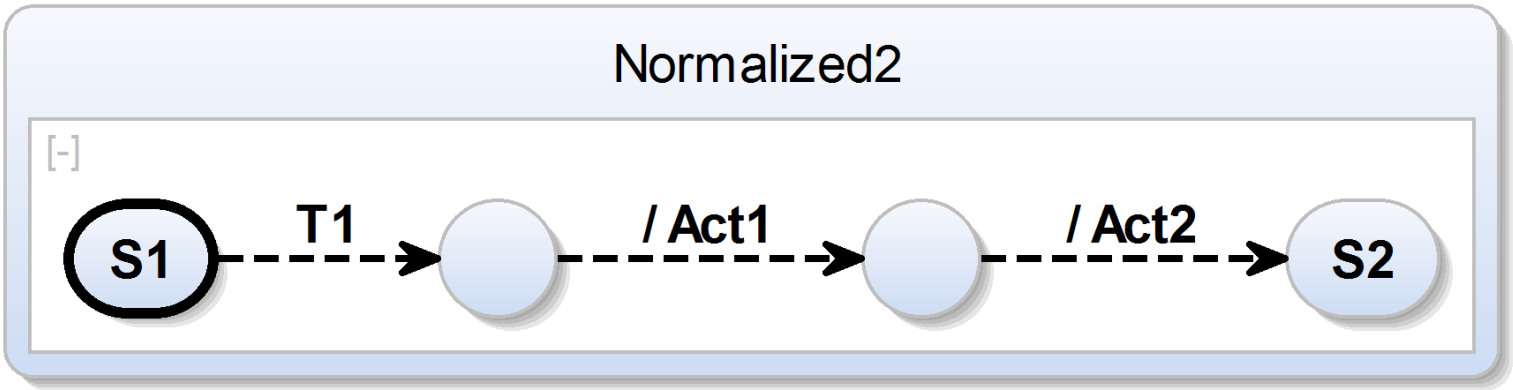
Actions Normalization (cont'd)



Actions Normalization (cont'd)



Core SCChart before normalization

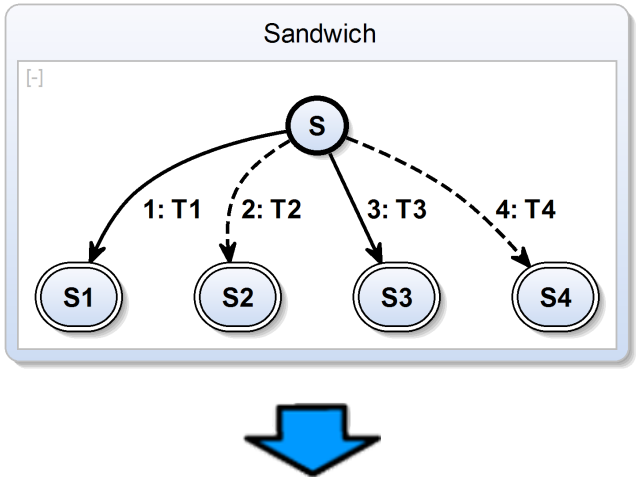


Core SCChart after normalization

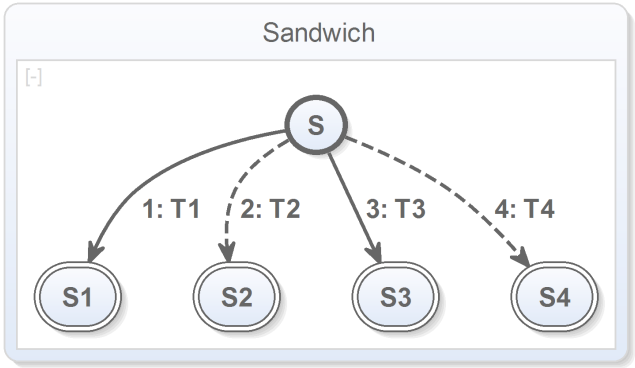
Actions Normalization Implementation Example

```
1  def void transformTriggerActions(Transition transition) {
2    if (((transition.trigger != null || !transition.immediate)
3         && !transition.actions.nullOrEmpty) || transition.actions.size > 1) {
4
5      val targetState = transition.targetState
6      val parentRegion = targetState.parentRegion
7      val transitionOriginalTarget = transition.targetState
8
9      var Transition lastTransition = transition
10
11     for (action : transition.actions.immutableCopy) {
12
13       val actionState = parentRegion.createState(targetState.id + action.id)
14       actionState.setTypeConnector
15
16       val actionTransition = createImmediateTransition.addAction(action)
17       actionTransition.setSourceState(actionState)
18
19       lastTransition.setTargetState(actionState)
20       lastTransition = actionTransition
21      }
22
23      lastTransition.setTargetState(transitionOriginalTarget)
24   }
25 }
```

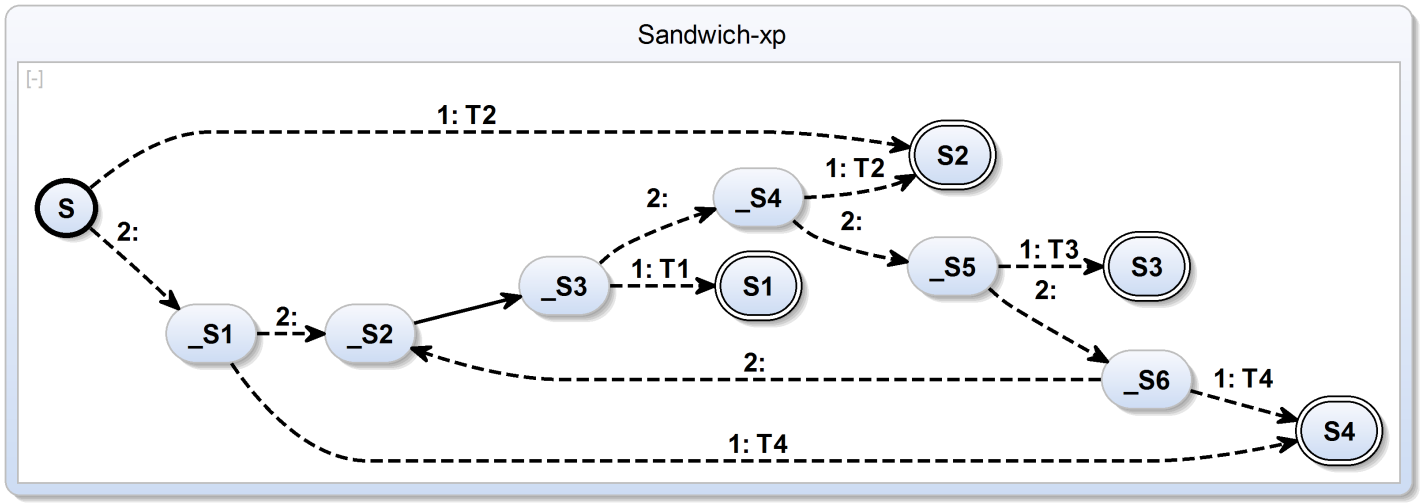
Trigger Normalization



Trigger Normalization

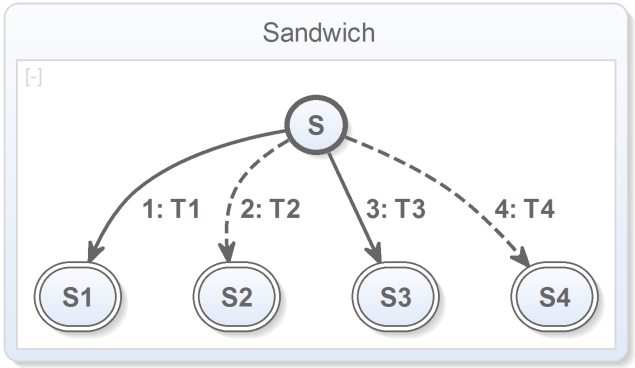


Core SCChart before normalization

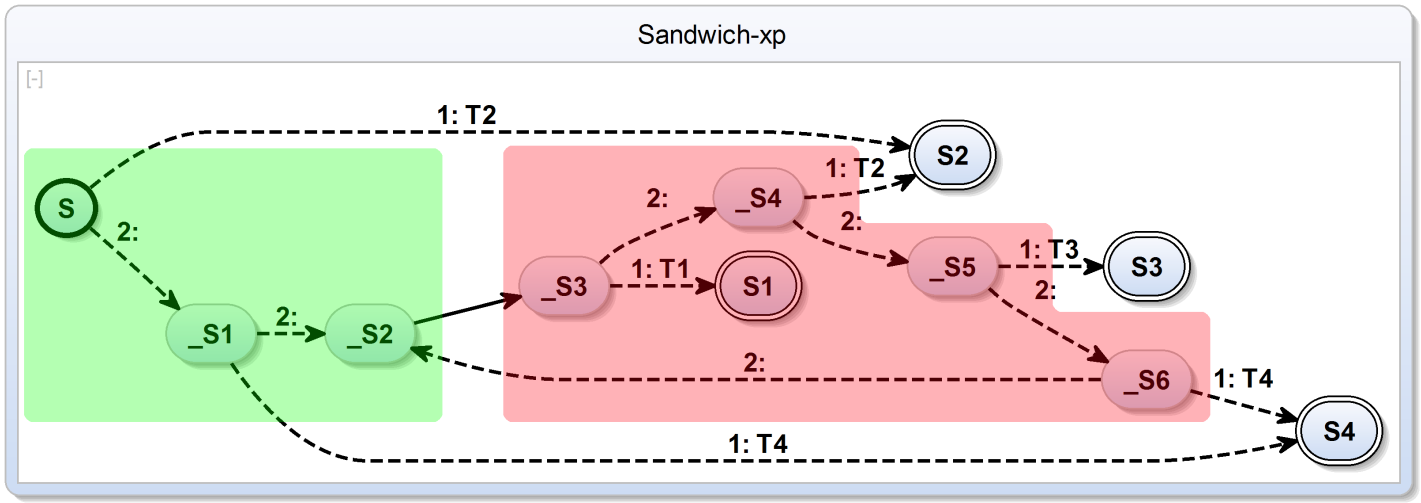


Core SCChart after normalization

Trigger Normalization

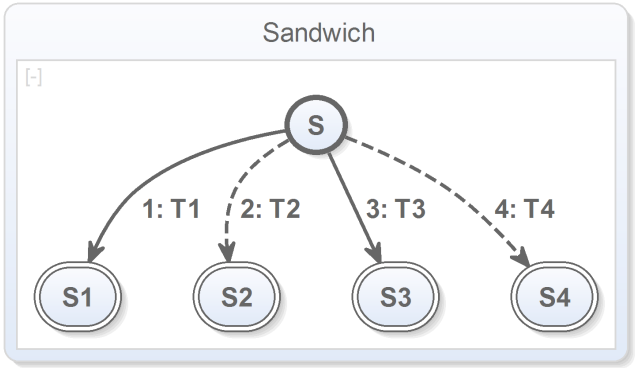


Core SCChart before normalization

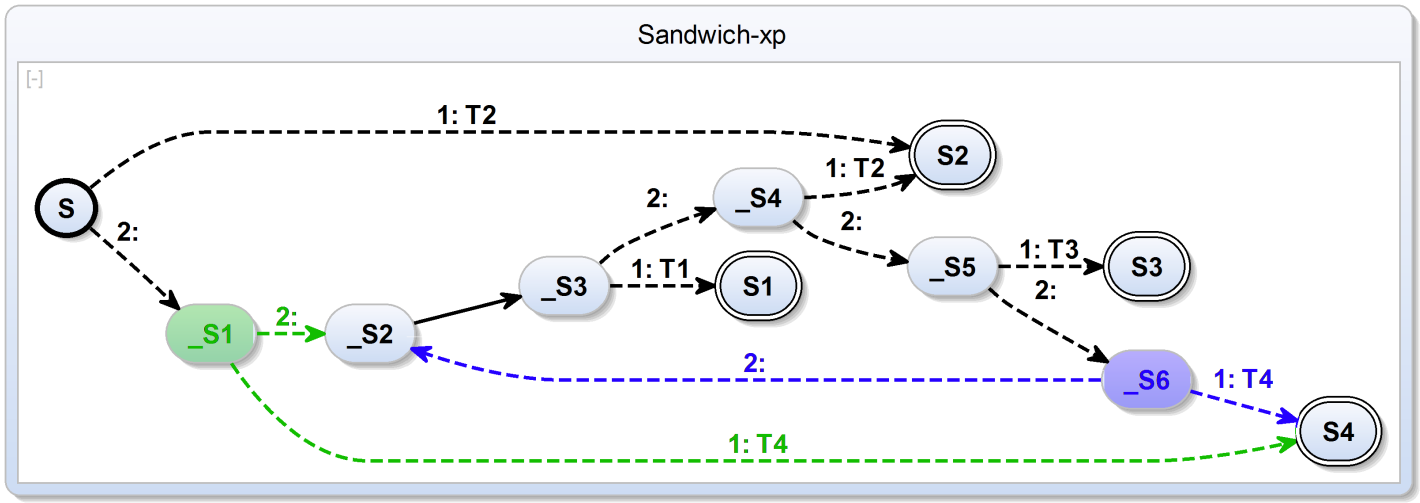


Core SCChart after normalization (Surface & Depth)

Trigger Normalization

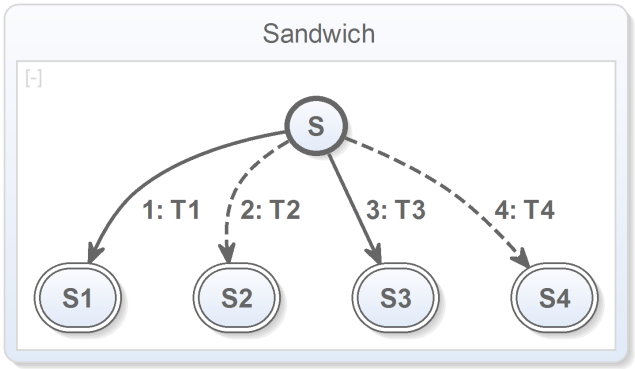


Core SCChart before normalization

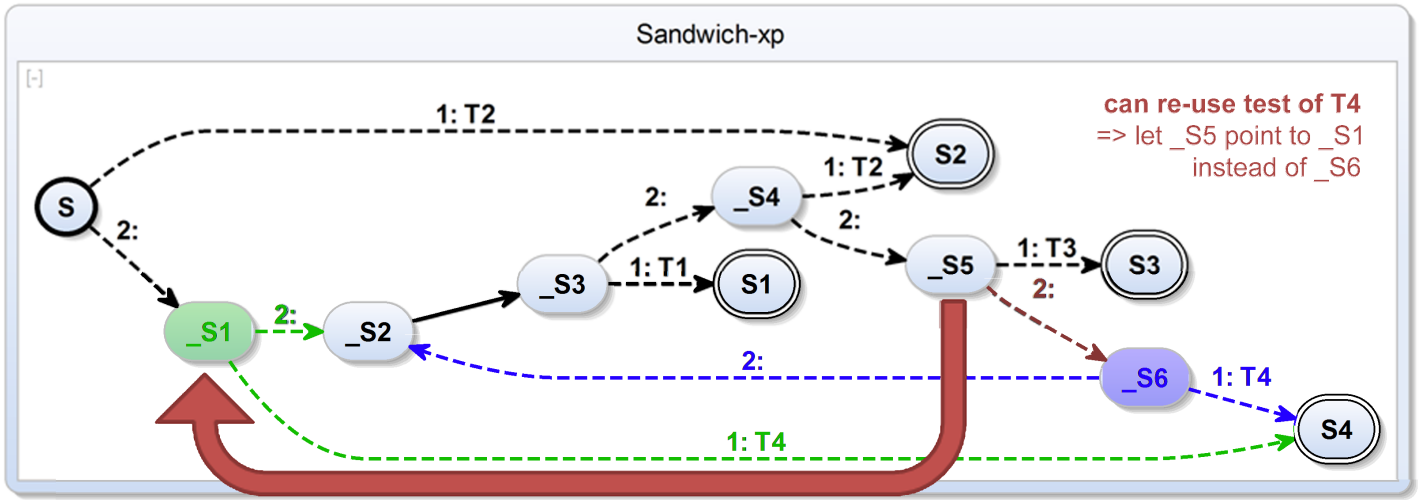


Core SCChart after normalization (potential optimization)

Trigger Normalization

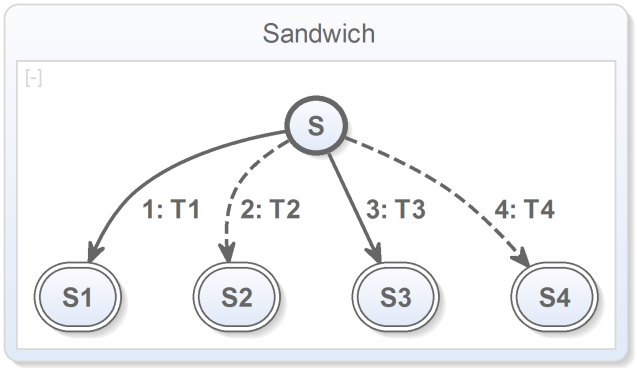


Core SCChart before normalization

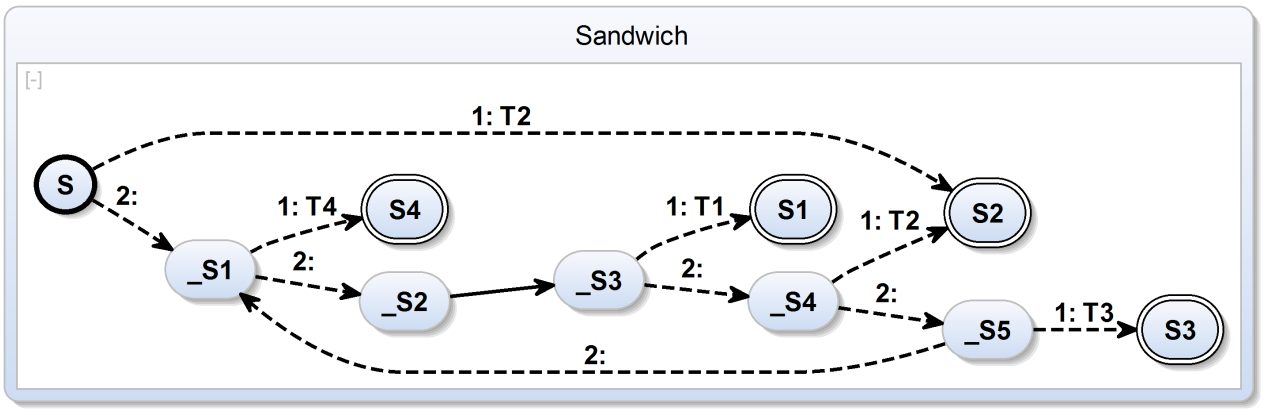


Core SCChart after normalization (potential optimization)

Trigger Normalization (Cont'd)

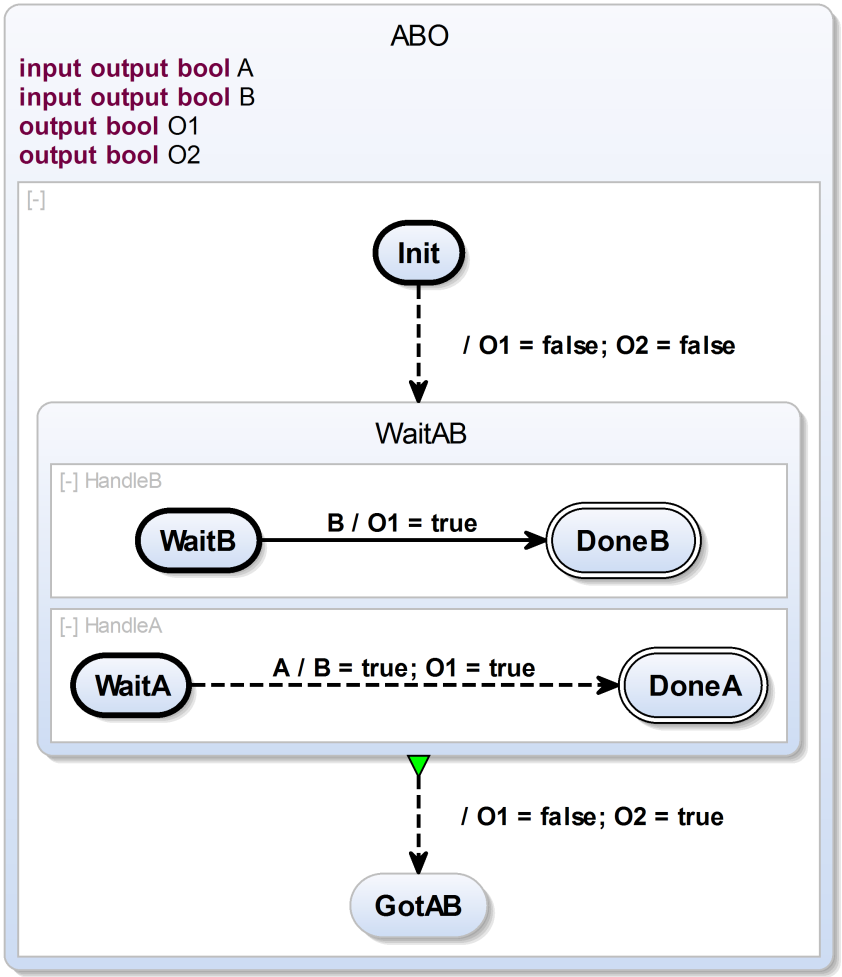


Core SCChart before normalization



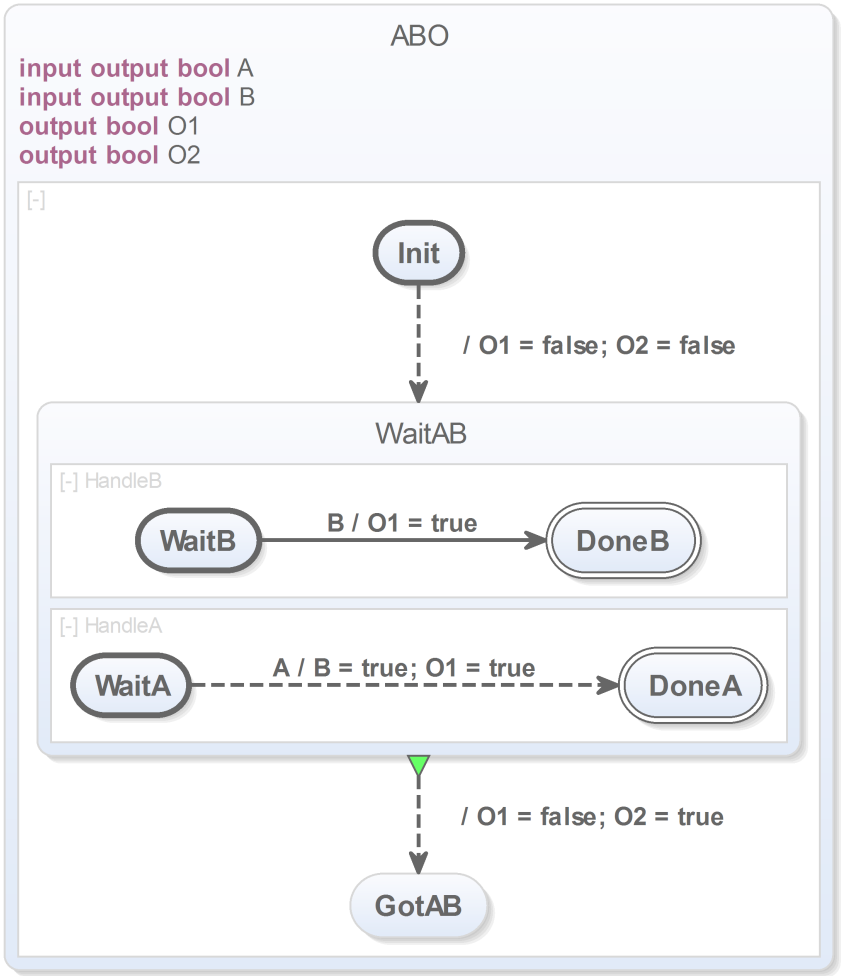
Core SCChart after optimized normalization

ABO — Normalization Example (Actions)

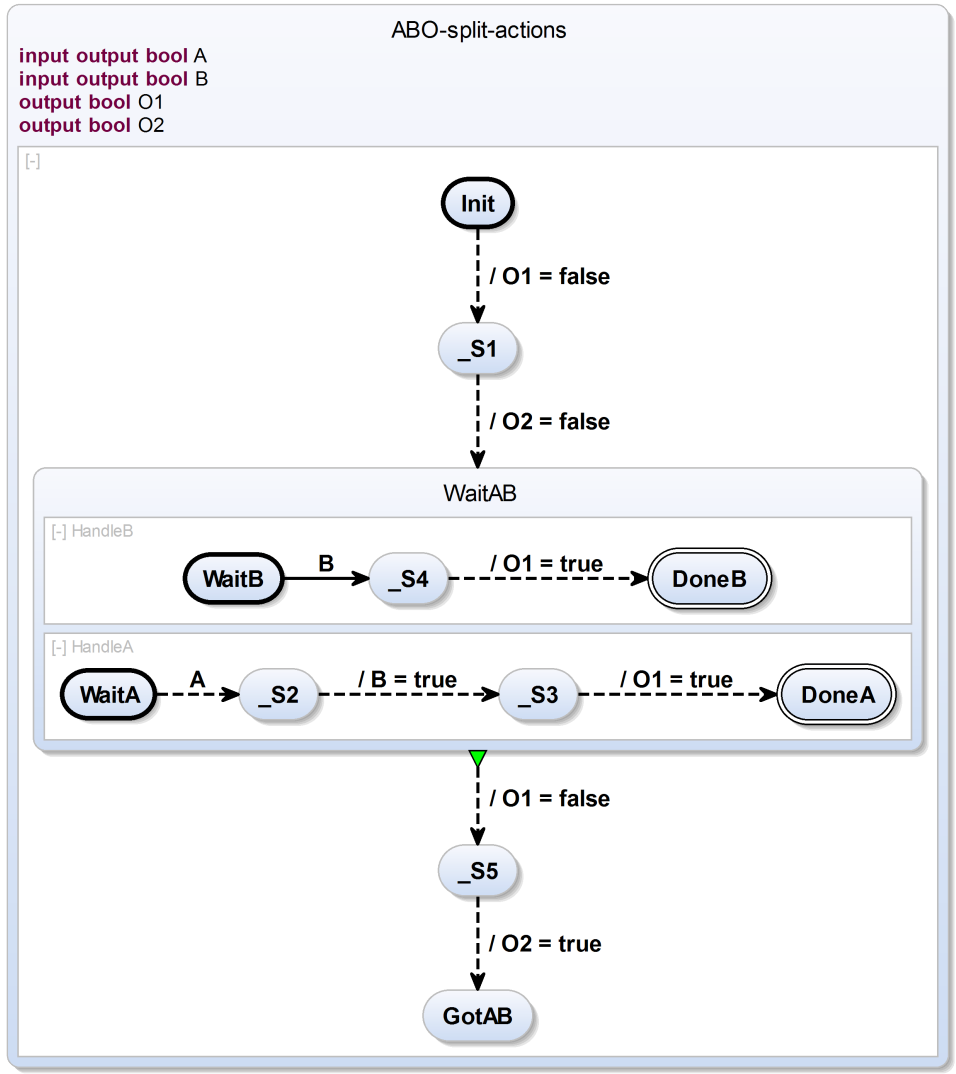


ABO Core SCChart

ABO — Normalization Example (Actions)

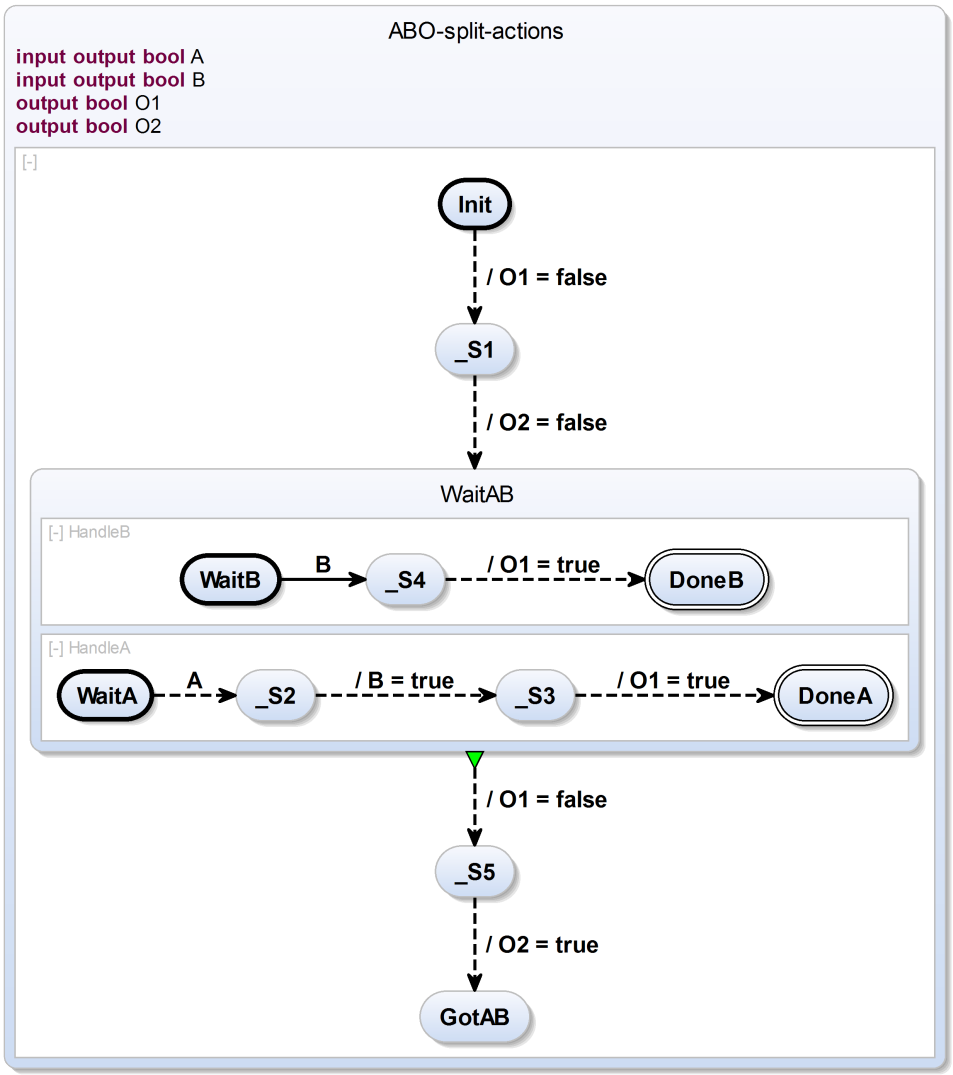


ABO Core SCChart



ABO Core SCChart with normalized actions

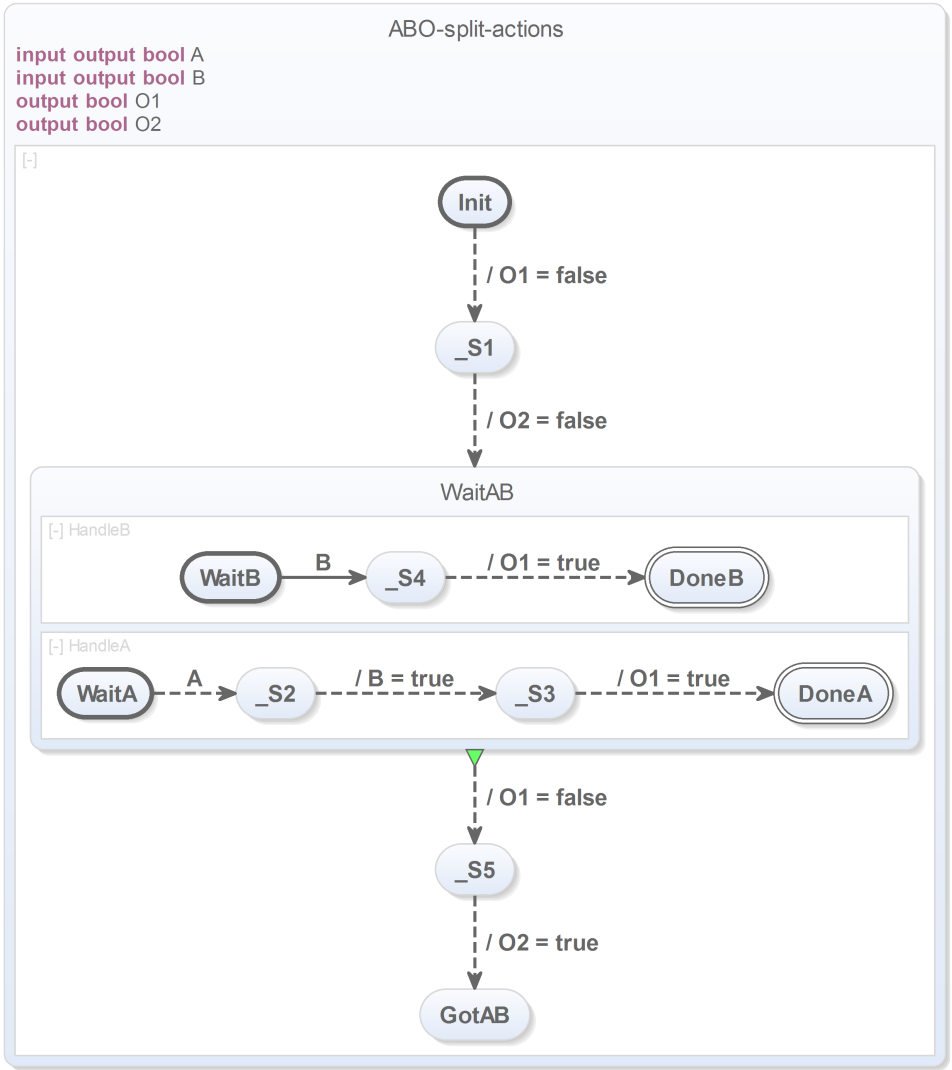
ABO — Normalization Example (Actions & Trigger)



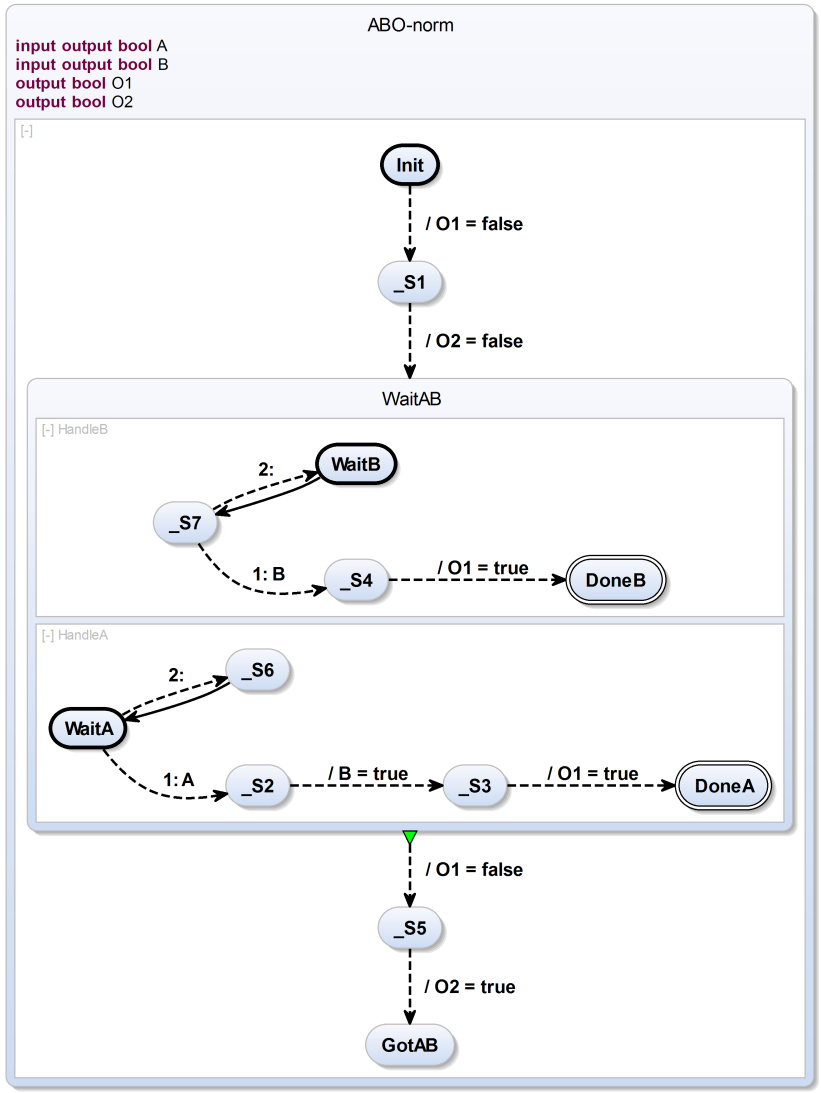
ABO Core SCChart with normalized actions

.

ABO — Normalization Example (Actions & Trigger)



ABO Core SCChart with normalized actions

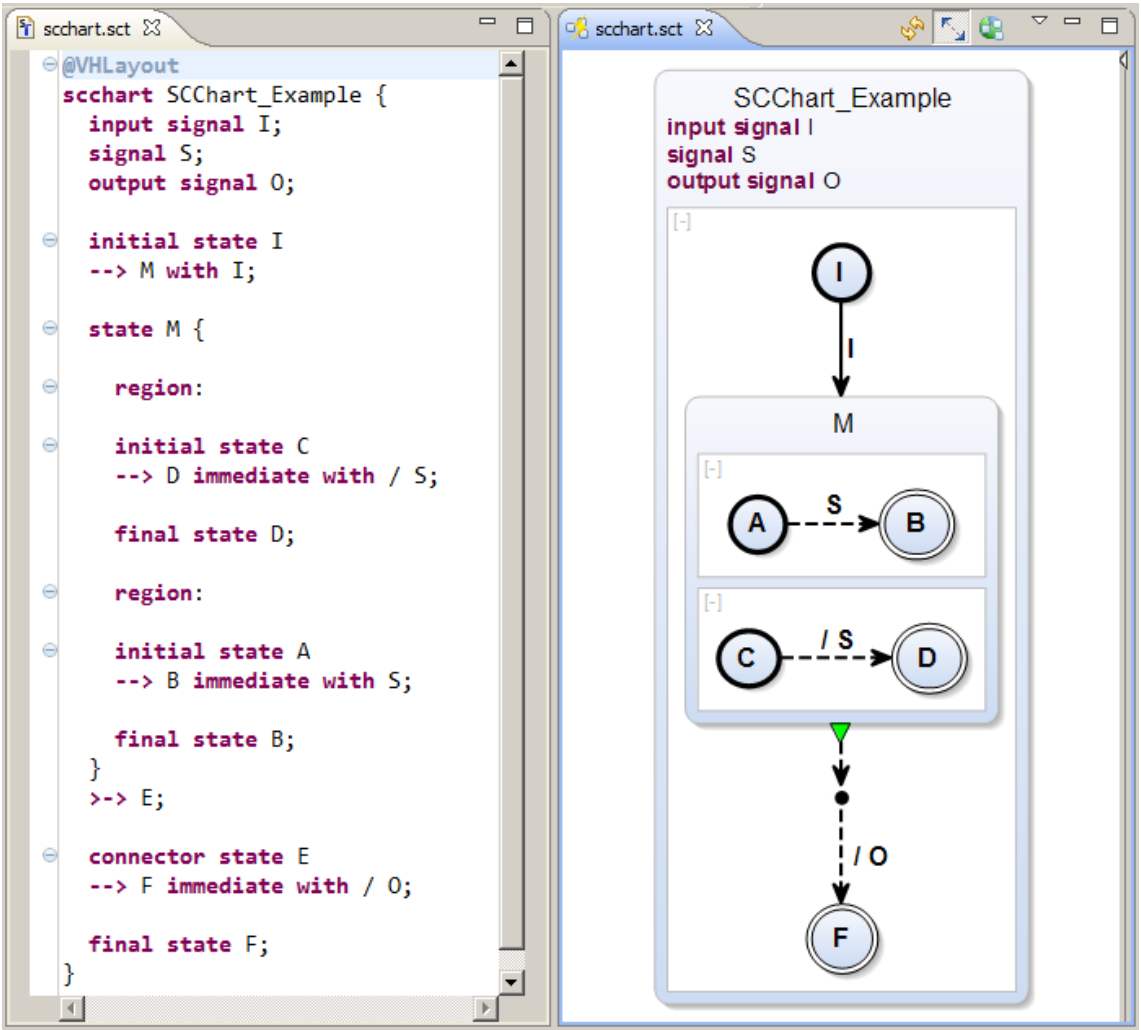


ABO Normalized SCChart

Overview

- SCCharts Overview
- Extended SCCharts → Core SCCharts
- Normalizing Core SCCharts
- Implementation in KIELER

Textual Modeling with KLighD



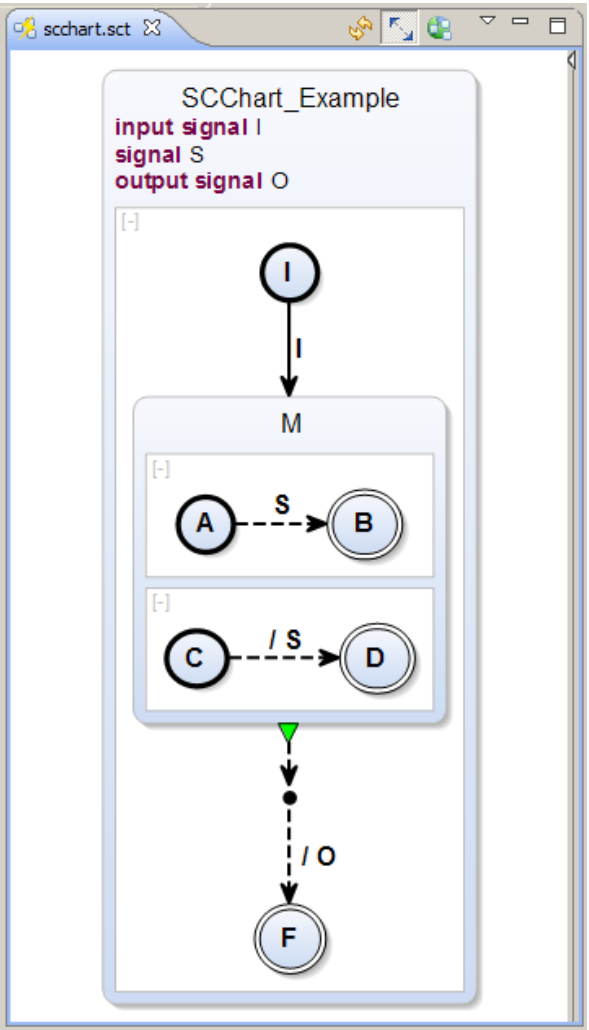
- Eclipse based KIELER framework

Textual Modeling with KLighD

scchart.sct

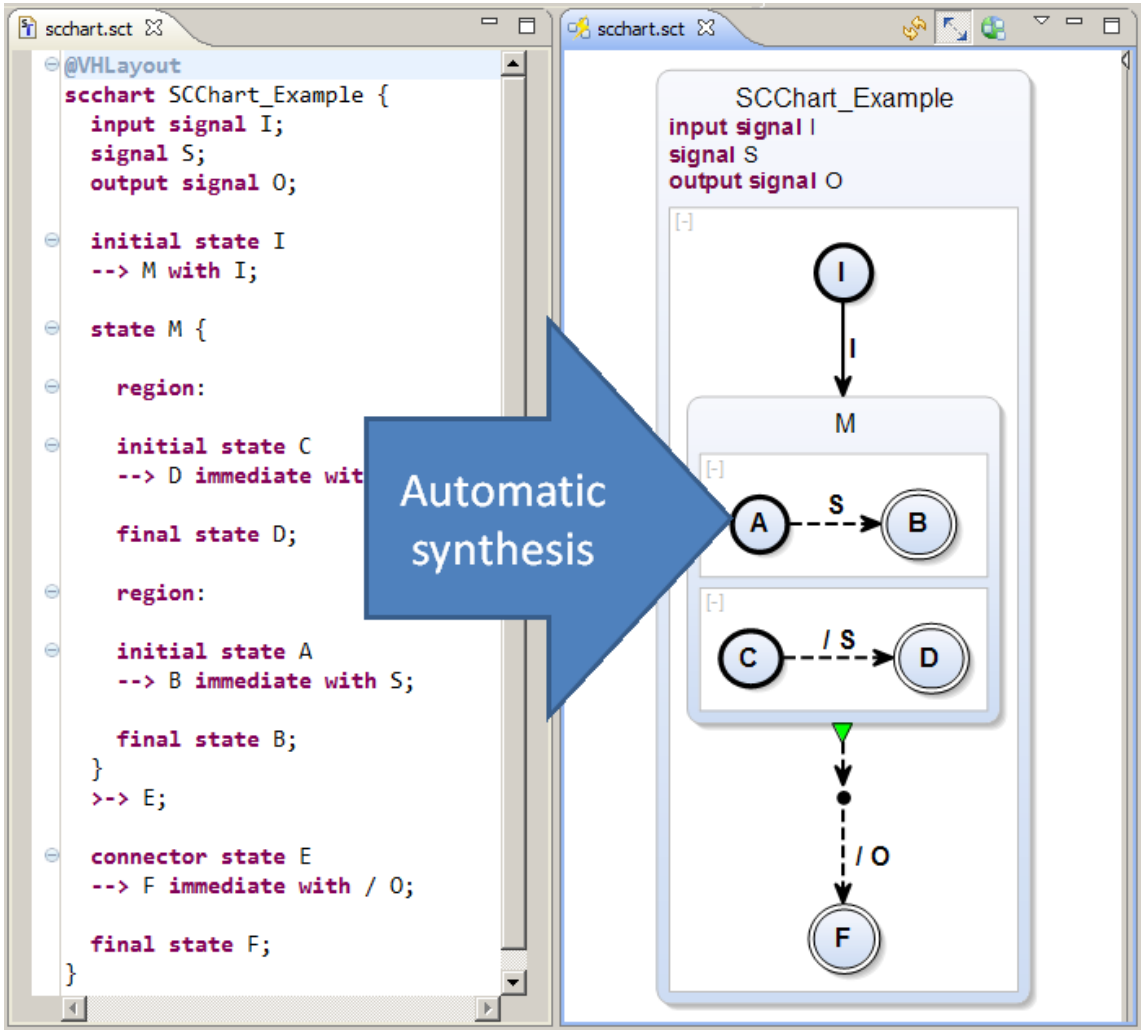
```
@VHLayout
scchart SCChart_Example {
  input signal I;
  signal S;
  output signal O;

  initial state I
  --> M with I;

  state M {

    region:

    initial state C
    --> D immediate with / S;

    final state D;

    region:

    initial state A
    --> B immediate with S;

    final state B;
  }
  >-> E;

  connector state E
  --> F immediate with / O;

  final state F;
}
```

scchart.sct



- Eclipse based KIELER framework
- Textual modeling based on Xtext
  - Syntax highlighting
  - Code completion
  - Formatter

Textual Modeling with KLighD



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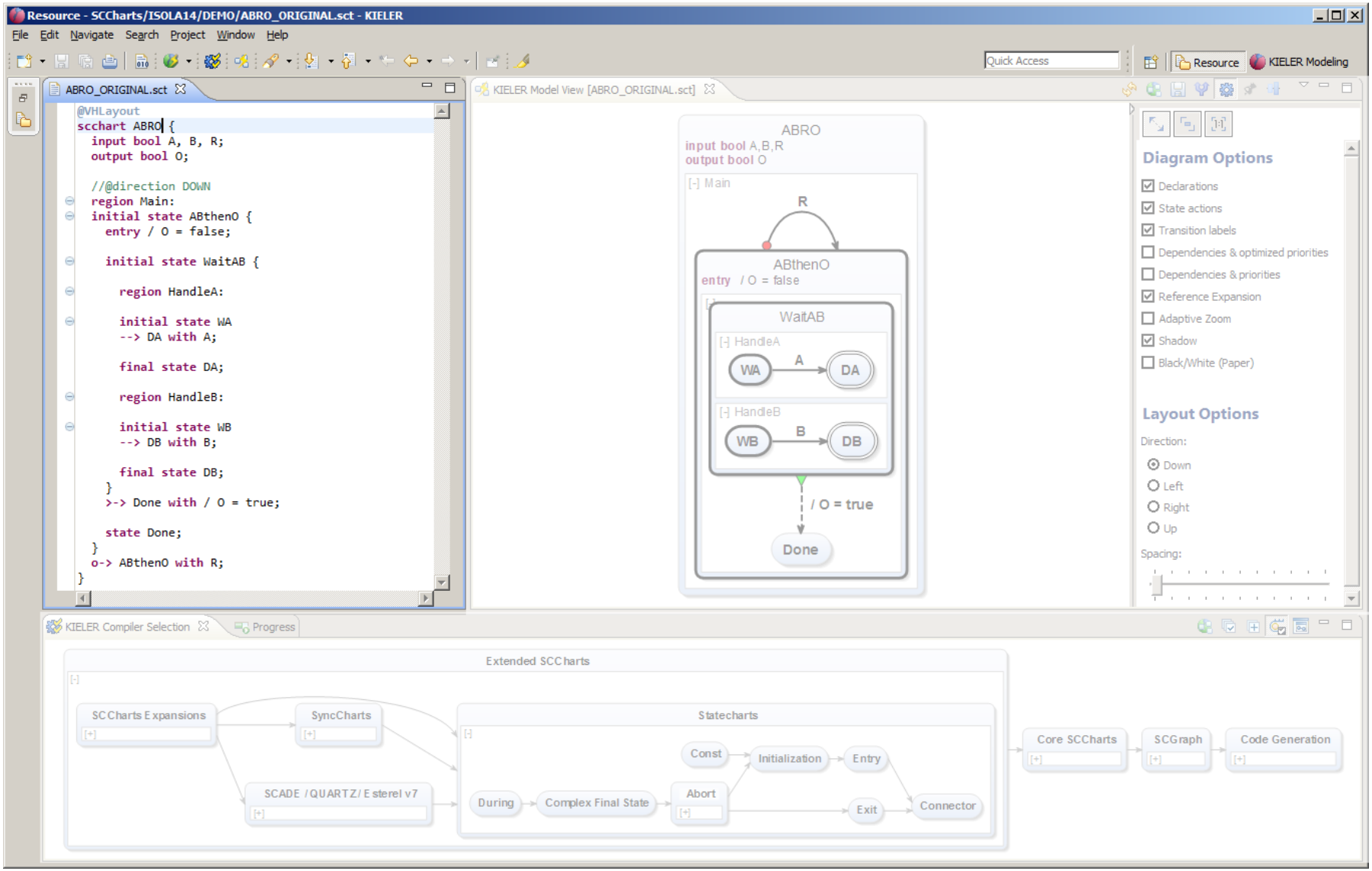
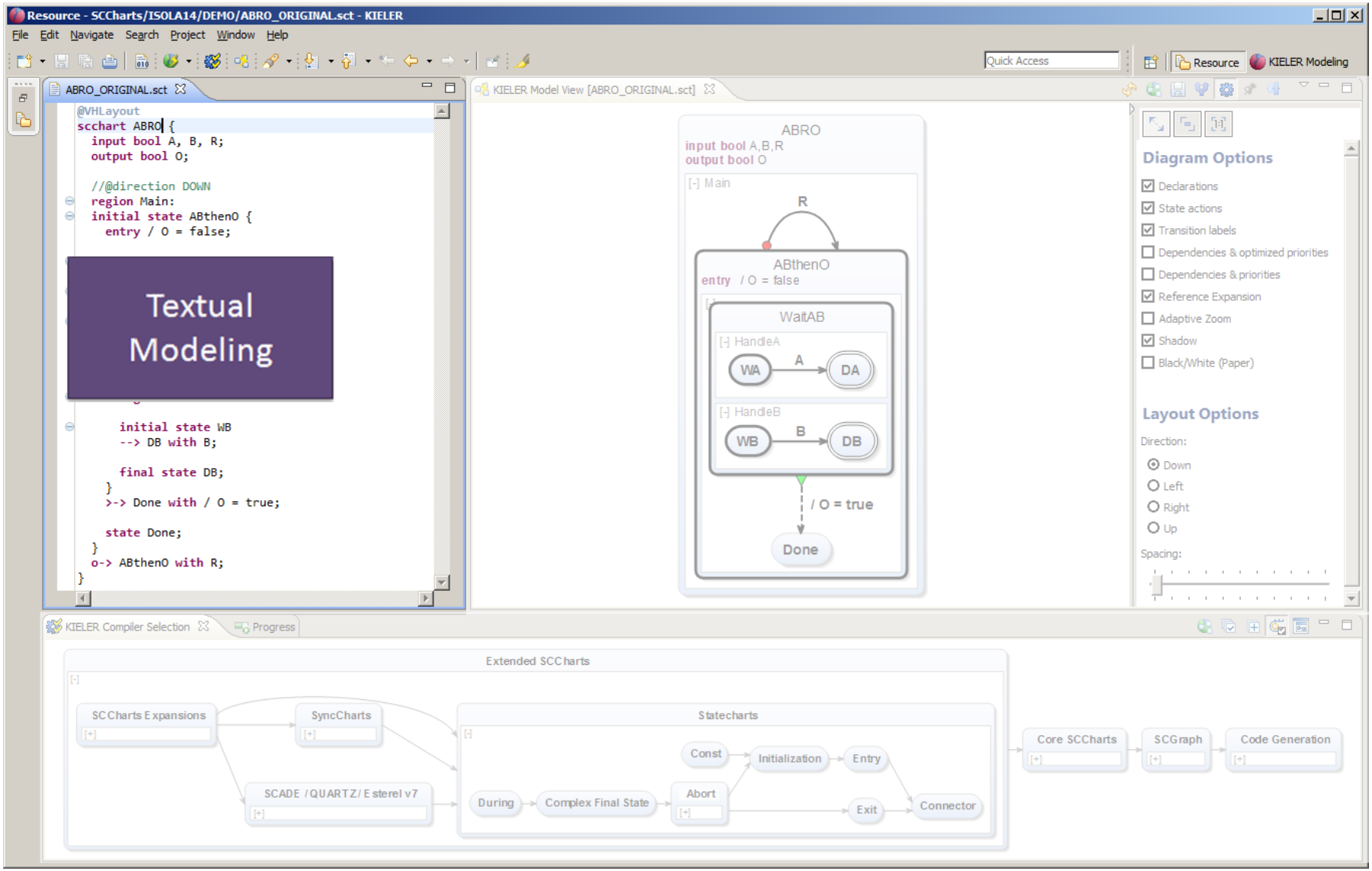
- Transient view based on KLighD

[C. Schneider et al., VL/HCC'13]

SCCharts Interactive Compilation



SCCharts Interactive Compilation



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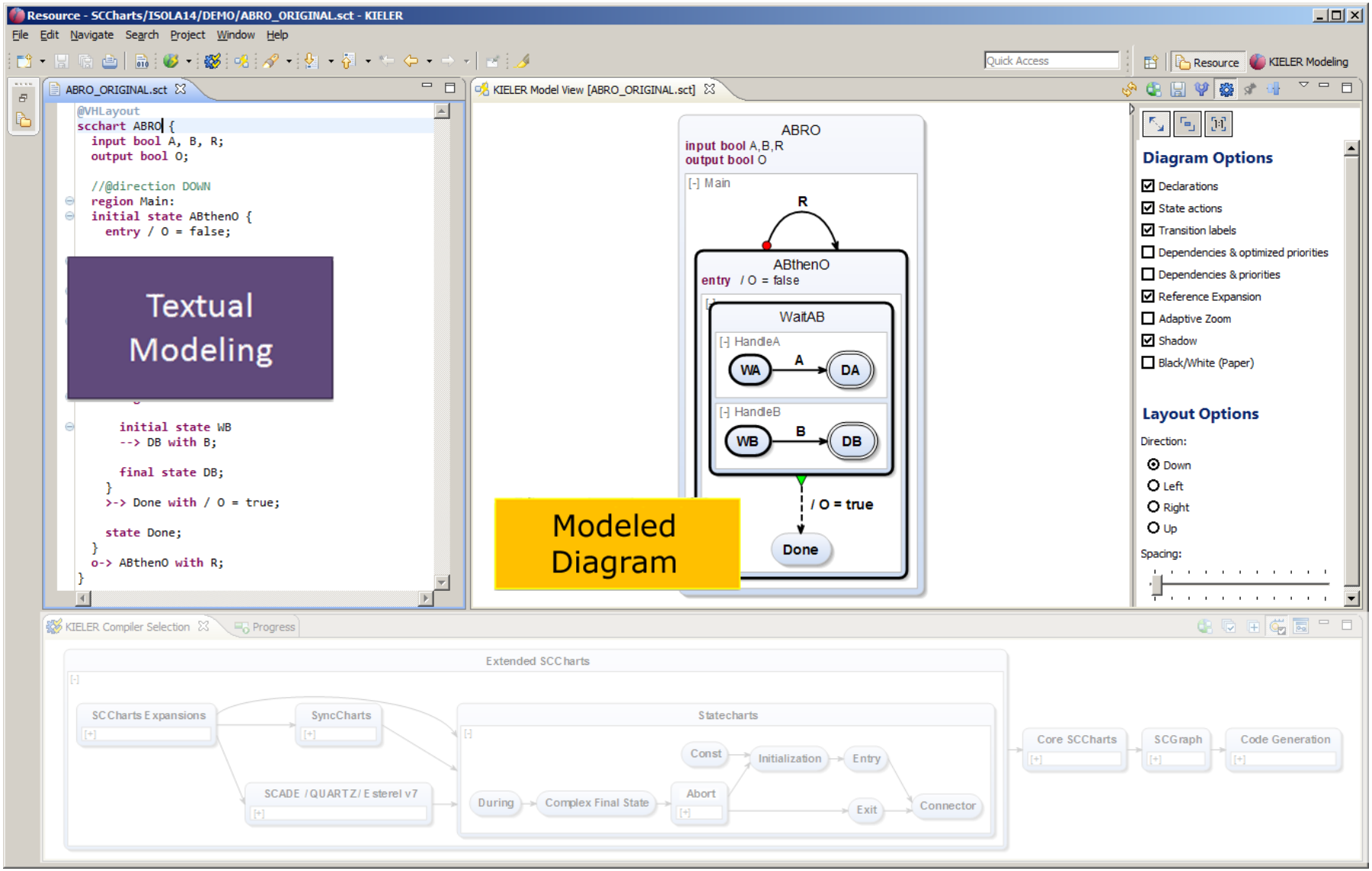
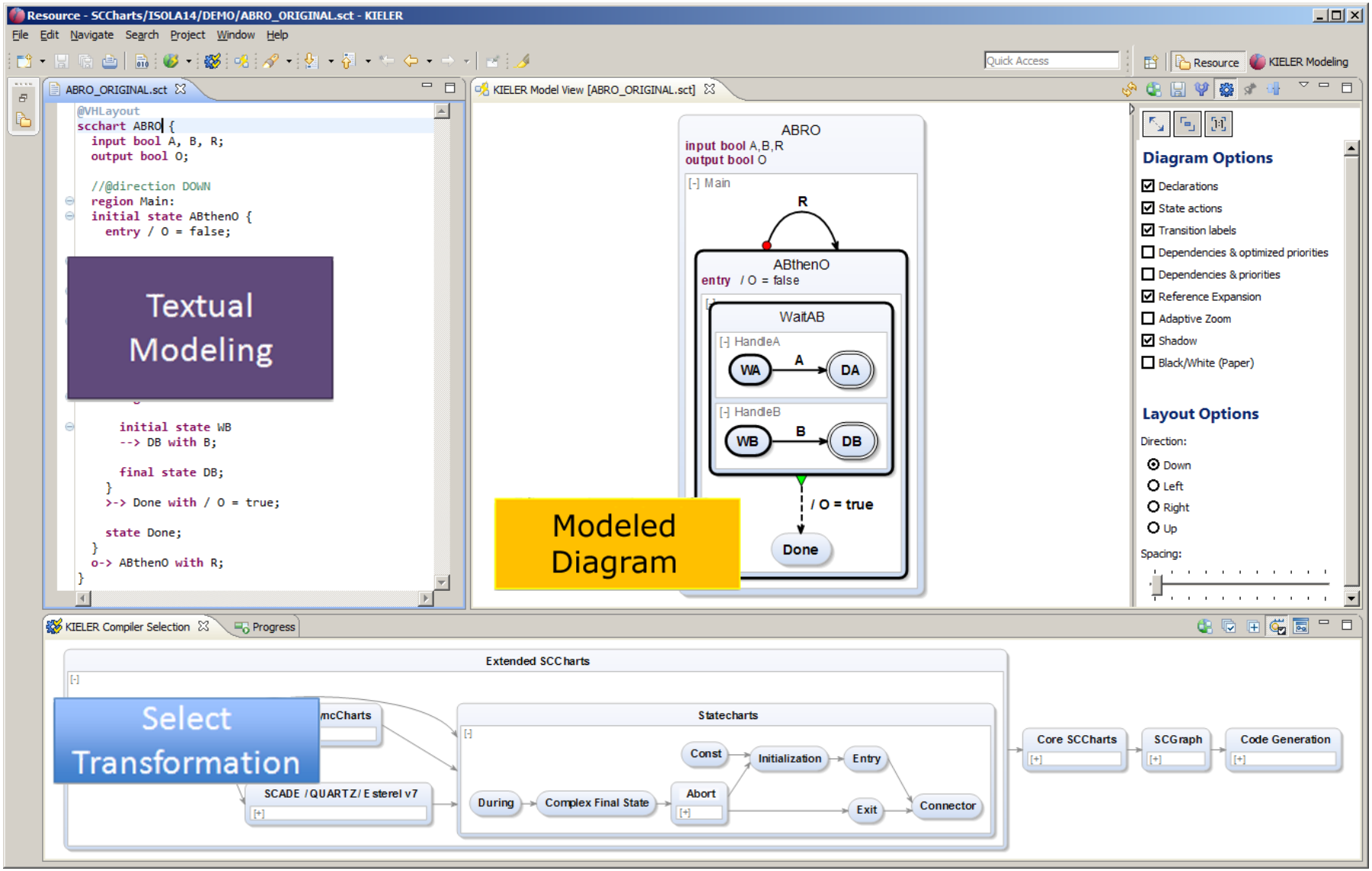


SCCharts Interactive Compilation



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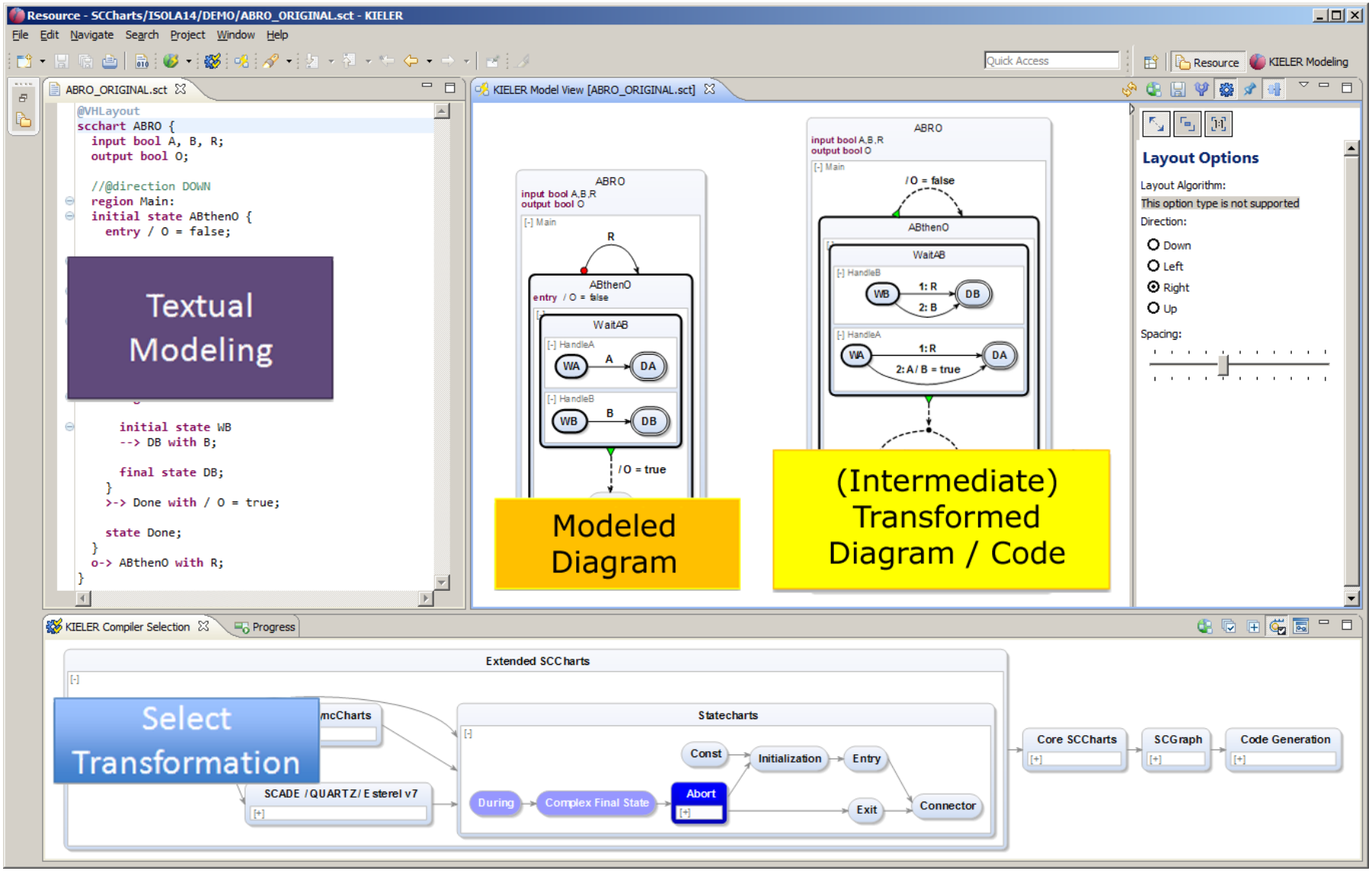
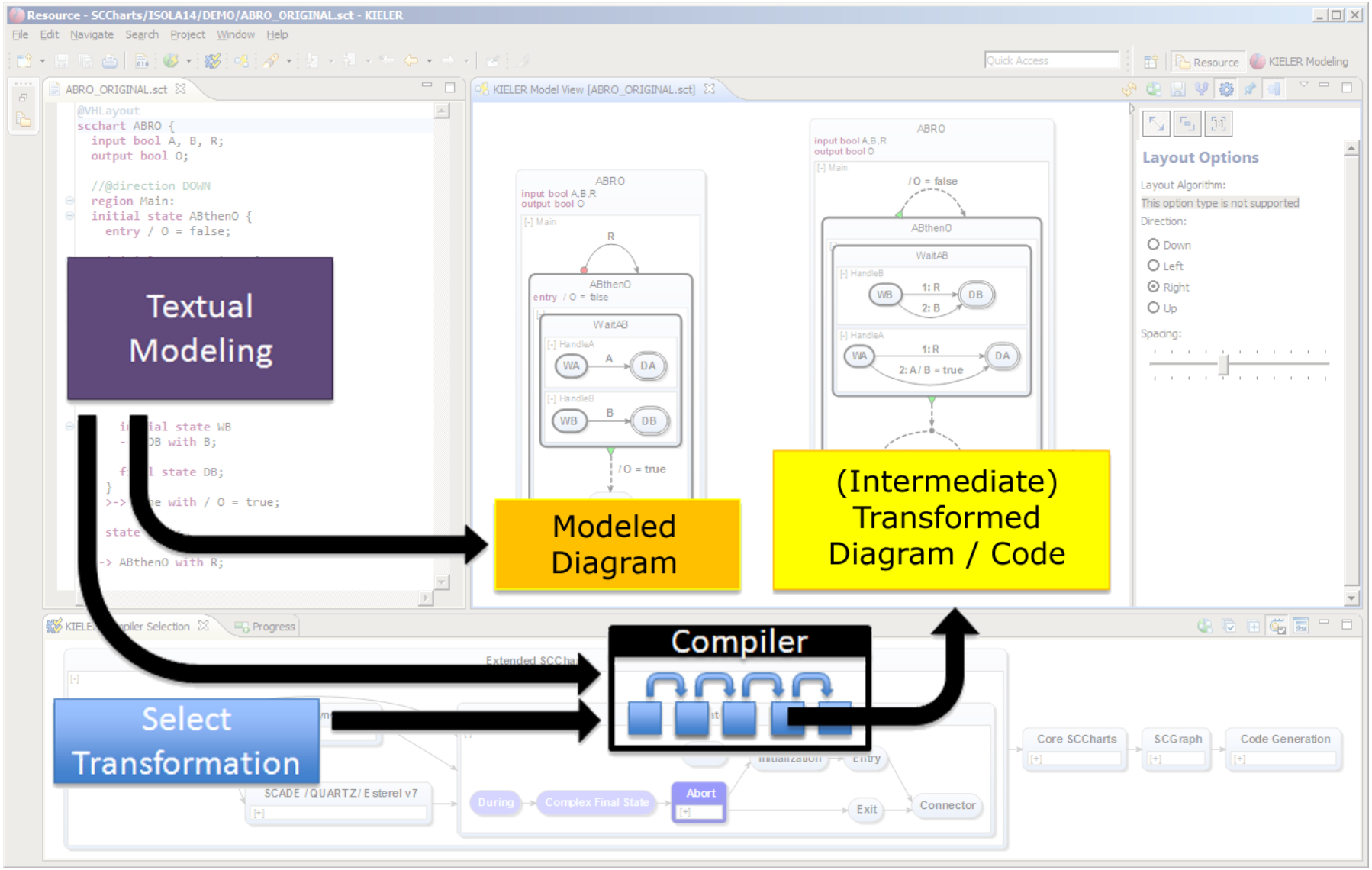


SCCharts Interactive Compilation



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- **Normalized** SCCharts: Further ease compilation

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  → Details in the next lecture :-)

To Go Further

- DFG-funded PRETSY Project: `www.pretsy.org`
- R. von Hanxleden, B. Duderstadt, C. Motika, S. Smyth, M. Mendler, J. Aguado, S. Mercer, and O. O'Brien. *SCCharts: Sequentially Constructive Statecharts for Safety-Critical Applications*. Proc. ACM SIGPLAN Conference on Programming Language Design and Implementation (PLDI'14), Edinburgh, UK, June 2014. `https://rtsys.informatik.uni-kiel.de/~biblio/downloads/papers/pldi14.pdf`
- C. Motika, S. Smyth and R. von Hanxleden, *Compiling SCCharts—A Case-Study on Interactive Model-Based Compilation*, Proc. 6th International Symposium on Leveraging Applications of Formal Methods, Verification and Validation (ISoLA 2014), Corfu, Greece, LNCS 8802, pp. 443–462 `https://rtsys.informatik.uni-kiel.de/~biblio/downloads/papers/isola14.pdf`