Synchronous Languages—Lecture 11

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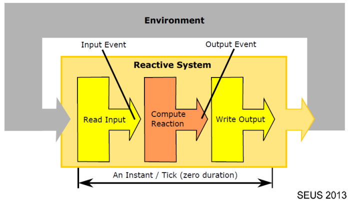
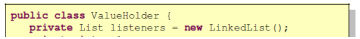
SCCharts — Sequentially Constructive Statecharts for Safety-Critical Applications

Reactive Embedded Systems



SEUS 2013

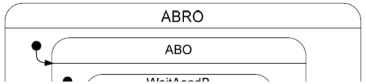
- Embedded systems react to inputs with computed outputs
- Typically state based computations
- Computations often exploit concurrency → Threads
- Threads are problematic → **Synchronous languages**: Lustre, Esterel, SCADE, SyncCharts

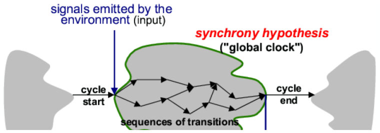


```
public class ValueHolder {
   private List listeners = new LinkedList();
```

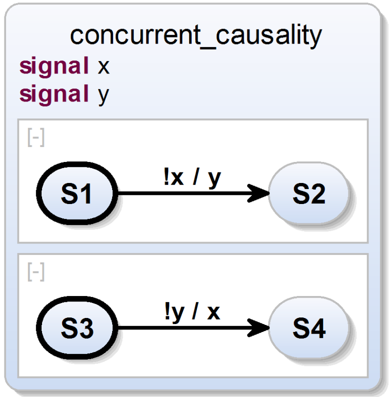
SyncCharts

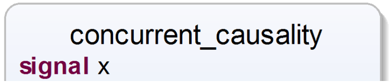
- Statechart dialect for specifying deterministic & robust concurrency
- SyncCharts:
  - Hierarchy, Concurrency, Broadcast
  - Synchrony Hypothesis
    1. Discrete ticks
    2. Computations: Zero time



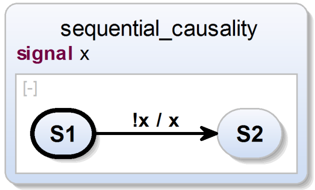


Causality in SyncCharts





Causality in SyncCharts (cont'd)



```
if (!done) {
  ...
  done = true;
}
```

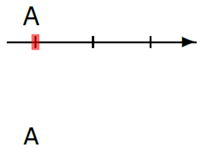
- Rejected by SyncCharts compiler
- *Signal Coherence Rule*
- May seem awkward from SyncCharts perspective, but common paradigm
- Deterministic sequential execution possible using *Sequentially Constructive MoC* → **Sequentially Constructive Charts (SCCharts)**

Overview

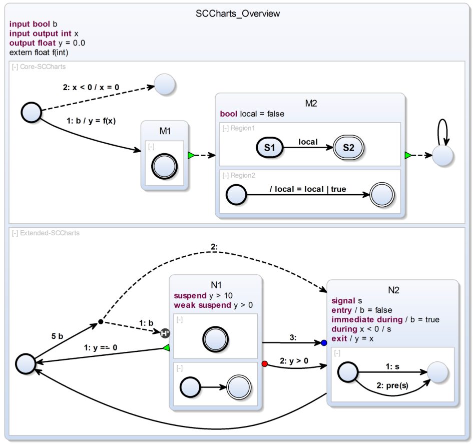
- SCCharts Overview
- Extended SCCharts → Core SCCharts
- Normalizing Core SCCharts
- Implementation in KIELER

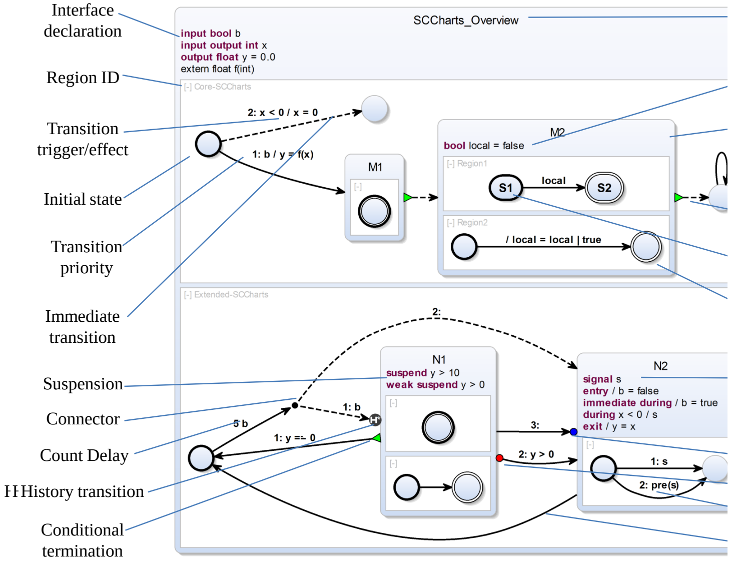
SCCharts Overview

- SCCharts $\widehat{=}$ SyncCharts syntax + Seqentially Constructive semantics
- *Hello World* of Sequential Constructiveness: **ABO**
  - Variables instead of signals
  - Behavior (briefly)
    1. Initialize
    2. Concurrently wait for inputs *A* or *B* to become *true*
    3. Once *A* and *B* are true after the initial tick, take *Termination*
    4. Sequentially set *O1* and *O2*

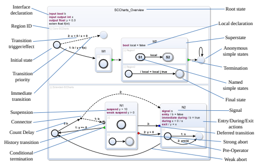


SCCharts — Features



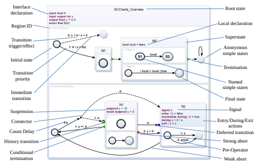


Motivation (Cont'd)



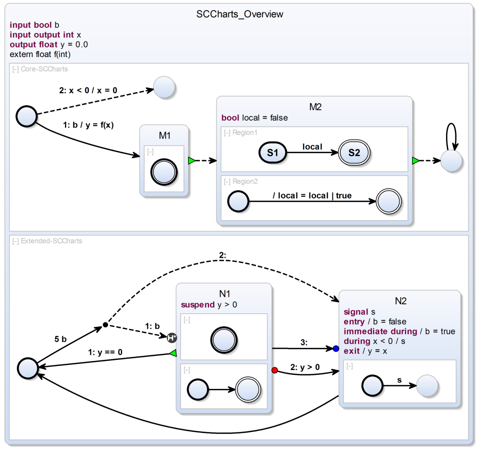
- **Advantages**:
  - Minimal base language (Core SCCharts) + advanced features (Extended SCCharts)
    - Similar to Esterel Kernel Statements & Statement Expansion
  - Advanced features are *syntactic sugar*
  - Extensible
  - Compilation (ongoing research)
    - Modular & extensible
    - Less complex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

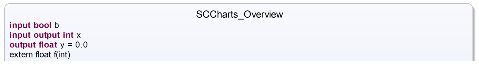
Motivation for Core SCCharts



- **Observation I**: Numerous features
  - ☺ Compactness / readability of models
  - ☹ Steeper learning curve
  - ☹ Direct compilation & verification more complex
- **Observation II**: Various features can be expressed by other ones
- **Consequence**: ⇒ Define extended features by means of base features

SCCharts — Core & Extended Features





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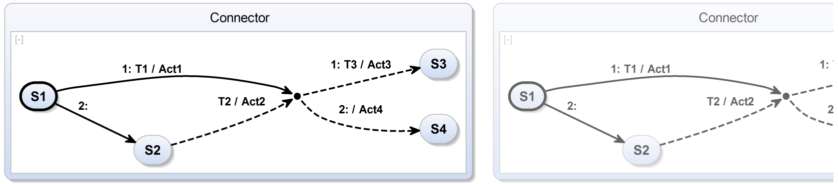
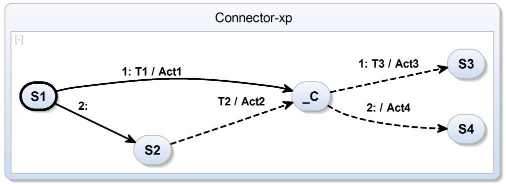
Transforming Connectors

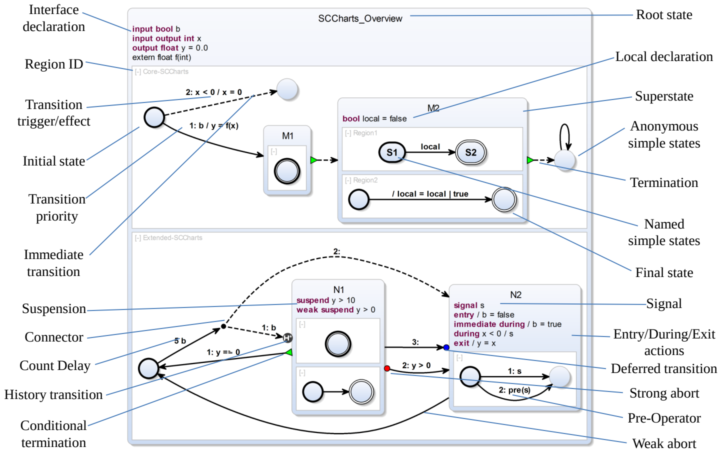


Extended SCCharts with Connectors

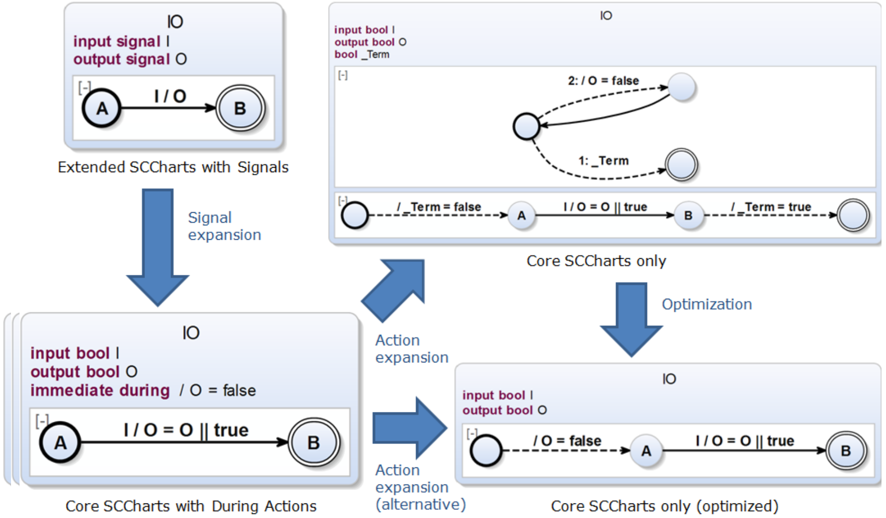


Core SCCharts without Connectors

SCCharts — Core Transformations Examples



Transforming Signals



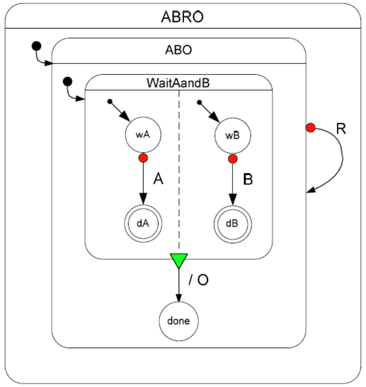
Extended SCCharts with Signals

Core SCCharts with During Actions

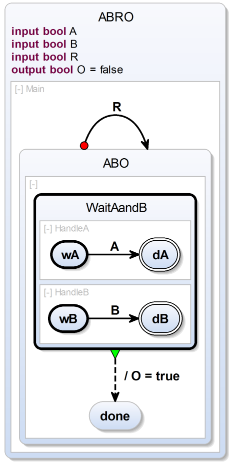
Core SCCharts only

Core SCCharts only (optimized)

SyncChart and SCChart ABRO

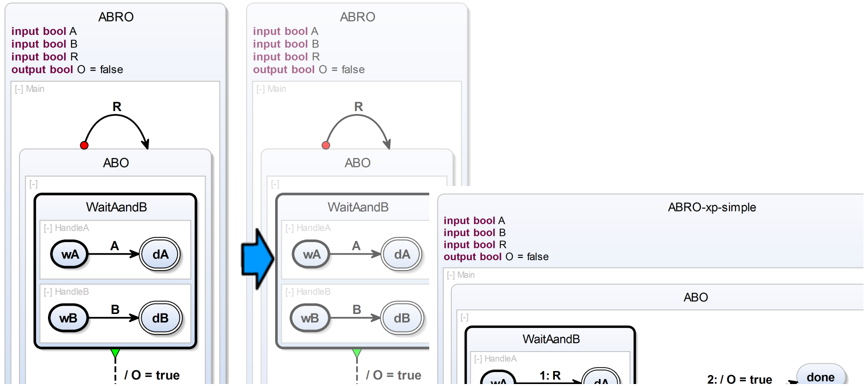


[Charles André, Semantics of SyncCharts, 2003]

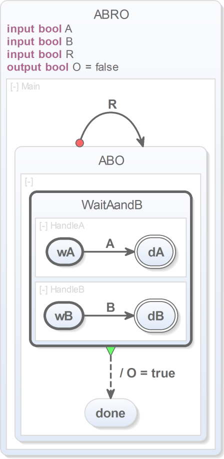


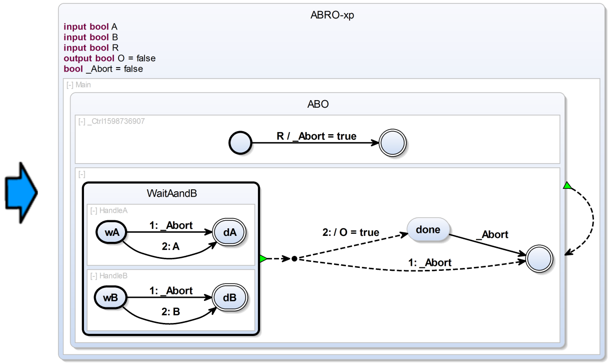
. ABRO SCChart

ABRO — Transforming Strong Aborts



ABRO — Transforming Strong Aborts (cont'd)

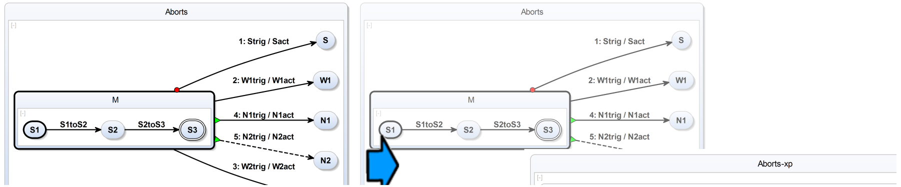




. Core SCChart without Strong Abort and WTO

ABRO SCChart with Strong Abort

Transforming General Aborts



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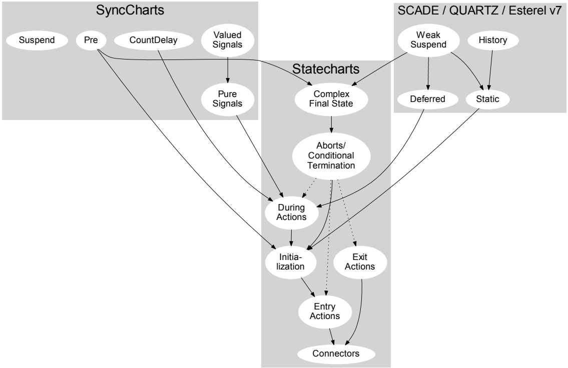
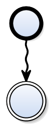
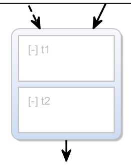
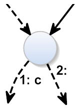
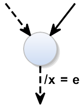
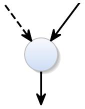
Single-Pass Language-Driven Incremental Compilation (SLIC)



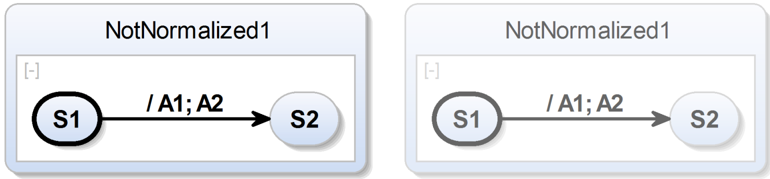
- Some core transformations will produce (use) some other extended features (solid lines)
- Other core transformations cannot handle some extended features (dashed lines)
- → Order in which core transformations are applied is important
- → Dependencies (do not have any cycle, which would be forbidden)

Normalization

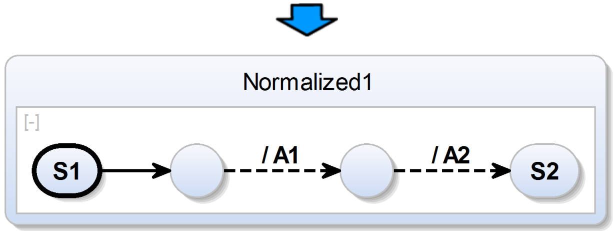
- Further simplify compilation process for Core SCCharts
- Allowed patterns:

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

Actions Normalization

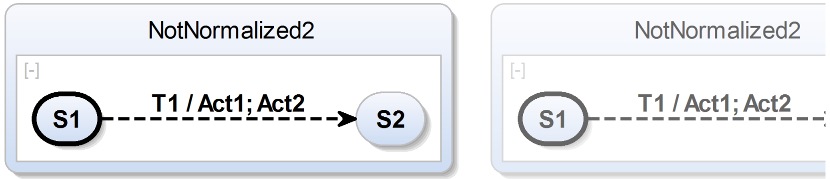


Core SCChart before normalization

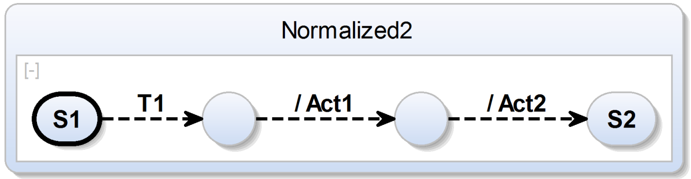


Core SCChart after normalization

Actions Normalization (cont'd)



Core SCChart before normalization

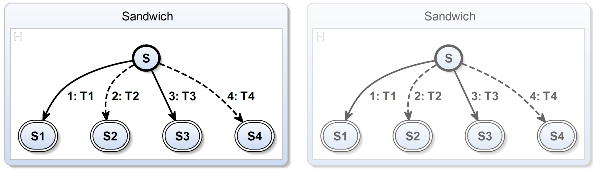


Core SCChart after normalization

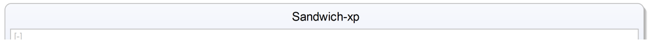
Actions Normalization Implementation Example

```
def void transformTriggerActions(Transition transition) {
  if (((transition.trigger != null || !transition.immediate)
      && !transition.actions.nullOrEmpty) || transition.actions.size > 1) {

    val targetState = transition.targetState
    val parentRegion = targetState.parentRegion
    val transitionOriginalTarget = transition.targetState

    var Transition lastTransition = transition

    for (action : transition.actions.immutableCopy) {

      val actionState = parentRegion.createState(targetState.id + action.id)
      actionState.setTypeConnector

      val actionTransition = createImmediateTransition.addAction(action)
      actionTransition.setSourceState(actionState)

      lastTransition.setTargetState(actionState)
      lastTransition = actionTransition
    }

    lastTransition.setTargetState(transitionOriginalTarget)
  }
}
```

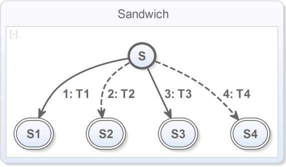
Trigger Normalization



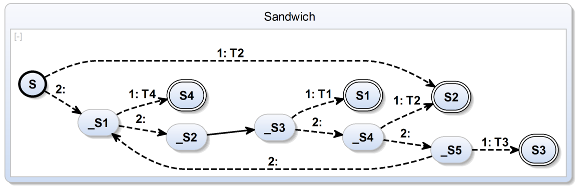
Core SCChart before normalization



Trigger Normalization (Cont'd)

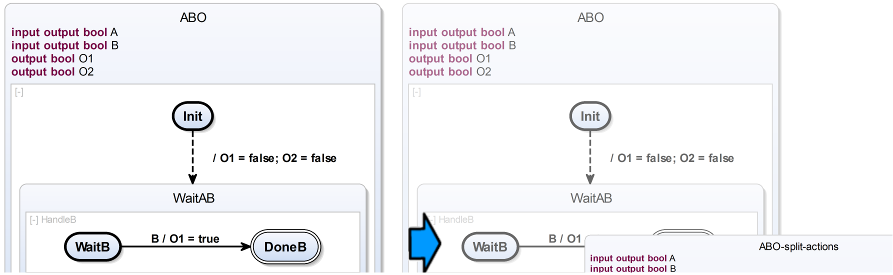


Core SCChart before normalization

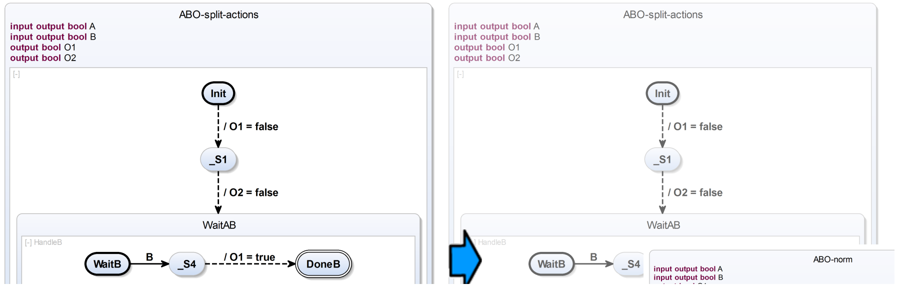


Core SCChart after optimized normalization

ABO — Normalization Example (Actions)



ABO — Normalization Example (Actions & Trigger)



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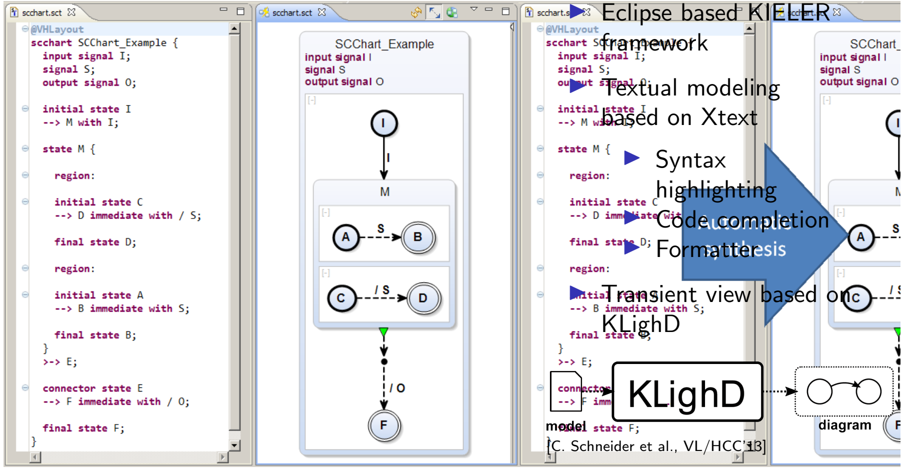
Textual Modeling with KLighD

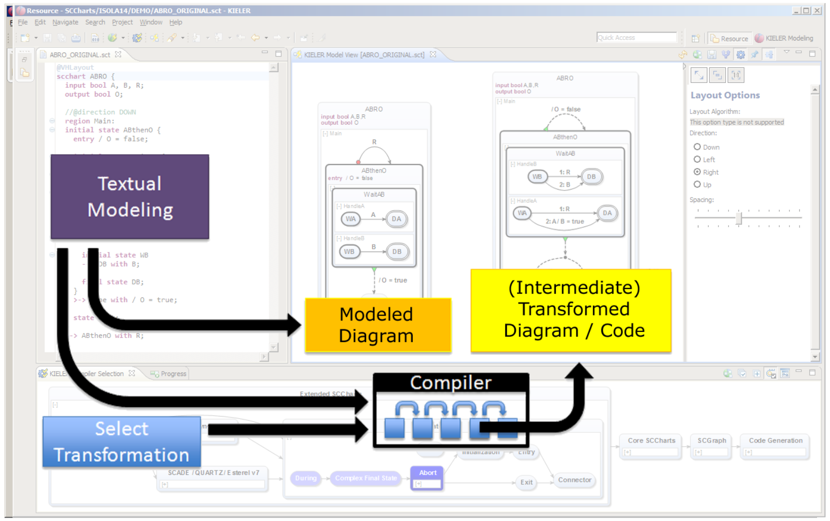


```
@VHLayout
scchart SCChart_Example {
  input signal I;
  signal S;
  output signal O;

  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;
}
```

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

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

SCCharts Interactive Compilation



Resource - SCCharts/ISOLA14/DEMO/ABRO_ORIGINAL.sct - KIELER

ABRO_ORIGINAL.sct

```
@VHLayout
scchart ABRO {
  input bool A, B, R;
  output bool O;

  //@direction DOWN
  region Main:
  initial state ABthenO {
    entry / O = false;

    in  ial state WB
    -   DB with B;

    f   l state DB;
  }
  >->   ne with / O = true;

  state

  -> ABthenO with R;
```

Conclusions

- SyncCharts **are** a great choice for specifying deterministic control-flow behavior. . .
- . . . but do not accept sequentiality
  `If (!done) { ... ; done = true;}`
- **SCCharts** extend SyncCharts w.r.t. semantics
  → Sequentially Constructive MoC
  - All valid SyncCharts interpreted as SCCharts **keep** their meaning
- **Core** SCCharts: Few basic features for simpler & more robust compilation
- **Extended** SCCharts: Syntactic sugar, readability, extensible
- **Normalized** SCCharts: Further ease compilation
  → Details in the next lecture :-)

To Go Further

- 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`