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LiComR 2003 Summer

Visual Formal Methods Survey

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Contents

- **Introdunction**
  - What is Visual Formalism?
  - Pros vs Cons
- **State-based Specification.**
  - Statecharts
  - SyncCharts
  - GCSR(Graphical Communication Shared Resource)
  - UPPAL

Visual Formalism(1/2)

- **Visual Formalism**
  - Graphical notations
  - Formal semantics
    - Formal specification
    - Formal verifications
  - Class
    - State-based specification
    - Communication-based specification
    - Etc

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Visual Formalism(2/2)

- **Merit vs demerit**
  - Merit
    - Comprehensive
    - Effectiveness
    - Readability
- **Demerit**
  - Complexity…
  - Verifiability

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State-based Specification(1/2)

- **Describe behavior of a system in terms of possible states and transitions**
  - Capture the condition of a system in terms of its state
- **State-based specification techniques have:**
  - Explicit description and complete coverage of states and transitions
  - Specification language and formal reasoning
  - Precise mathematics
  - Analysis tools

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State-based Specification(2/2)

- **Benefits**
  - Objectives
    - Clarify requirements
    - Locate and correct inconsistency and non-determinism
    - Refine requirements consistently into design
    - Decomposition of system
    - Prove or disprove assertions about system behavior
  - End Result
    - Predictably safe systems, more deterministic behavior
    - Links between customer needs and system design

State-based Specification-Concepts(1/2)

- **State**
  - *A* state represents the computational readiness of *a system at that instance of time during its lifetime*
- **Initial state**
  - The state in which a system starts
- **Condition**
  - Represents an existing on-going state of the system
- **Quantification**
  - The application of a condition over more than one variable

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State-based Specification - Concepts (2/2)

- **Transition**
  - *A* transition is a change in the state of the system
- **Event**
  - An event is an instantaneous change in the environmental or internal condition of a system.
- **Action/activity**
  - The function that is carried out or the event that is emitted upon the transition of the system from one state to another
- **Invariant**
  - A global or local property that holds true for the duration of the system lifetime

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State-based Specification-Techniques and Methods

- Finite state machines
- Augmented transition networks
- SDL
- Petri nets
- Sequence diagrams
- Statecharts
- SyncCharts
- GCSR
- UPPAAL
- Computational tree logic
- UML state diagrams

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Statecharts

Intro. to Statecharts(1/3)

- **Developed by David.Harel in 1987**
  - “Statecharts: A Visual Formalism for Complex Systems” (1987)
- **Provide behavioral description of reactive systems**
  - Specification and design of discrete-event systems
  - *Hardware, Instrument and Control system, Embedded Systems, Automobile, Cellular phone,Missile, Avionics…*

“When event α occurs in state A and condition C is true, transfer state to B”

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Intro. to Statecharts(2/3)

- **Features**
  - An Extension of State Transition Diagram
  - Hierarchy, concurrency and communication
  - Uses area and location of graphical objects

Statecharts = State diagrams +
Hierarchy +
Orthogonality +
Broadcast-communication

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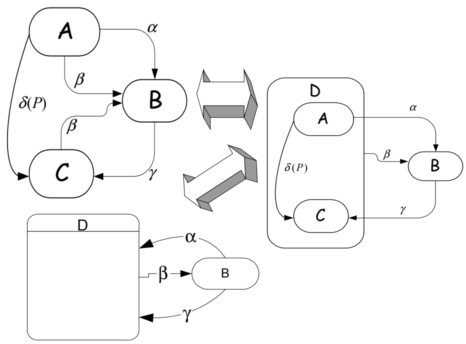
Intro. to Statecharts(3/3)

- **Clustering and refinement**



- States and transitions
- Arrow- labeled event and optionally a parenthesized condition
- Clustered two events to one
- D is an abstraction of A and C
- D can be refined to consist of A and C
- Zooming in and out of D (in latter A and C are not shown)

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Syntax of Statecharts(1/6)

- **States: Represent the mode of operation of an activity**
  - Hierarchy of states is represented y encapsulation of states.
- **Connectors**
  - Conditional : Shows branches to various possible states.
  - History: Remembers previously visited state.
- **Default transitions**
  - Specifies the initial state at each hierarchical level(assuming that an explicit transition was not taken).
- **Transition: Shows the possible paths from one state to another state.**

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Syntax of Statecharts(2/6)

- **Transitions Labels.**
  - Define the criteria needed for a transition to be taken from one state to another.
  - Specifies what action to perform when taking the transition
- **Trigger/Action syntax**
  - Trigger: causes the movement from one state to anther
    - Syntax of trigger:
      - **Event_expression and/or[condition_expression]**
  - Action: specifies what to do as a result of moving from one state to another.
    - Syntax of Action
      - **Action_expression1; Action_expression2;…**

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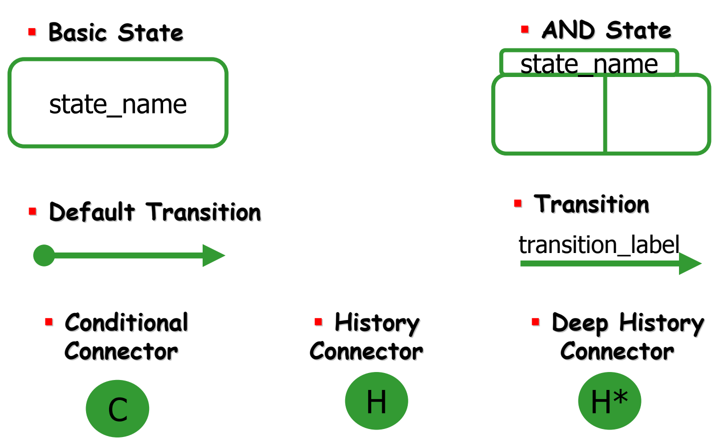
Syntax of Statecharts(3/6)



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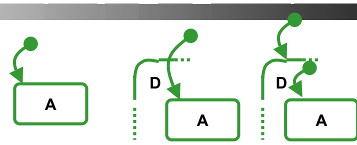
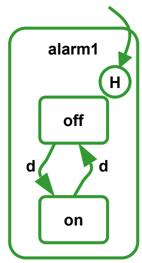
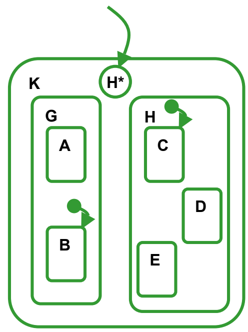
Syntax of Statecharts(4/6)

- **Default states**
  - Equivalent to start states for FSM



- **History**
  - (H) Record of the last state at the current level
  - (H*) Deep history stores last state at all levels current and below



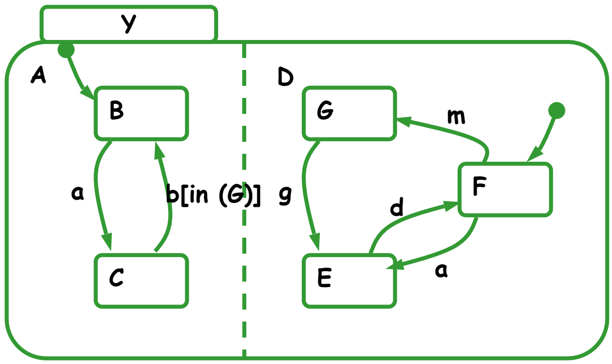


Syntax of Statecharts(5/6)

- **Orthogonality**
  - AND combination of states
  - Concurrency and synchronization
    - Simultaneous transitions in component states
  - Independence
    - Independent transition in one of the component state
  - Orthogonality = concurrency + independence
  - Communication among states by common events
  - Exits
    - Synchronized, independent and ε-transition exit

Syntax of Statecharts(6/6)

- **Orthogonality**



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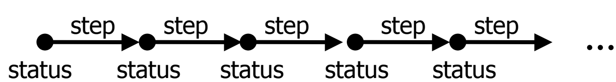
Semantic Characteristics of Statecharts(1/3)

- **Semantics of Statecharts in STATEMATE.**
  - how the model is executed.
- **Step semantics**



  - *Run*: a set of possible behavior
    - A series of snapshots of system responses to external environment stimuli
  - *Status*: a snapshot of system situation
  - *Step*: transition between two snapshots

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Semantic Characteristics of Statecharts(2/3)

- Events are sensed one step after it happened
  - Ex(S) is sensed one step after S was existed
- Reactions to events, and changes occurred within a step, can be sensed only after the step
- Events live in the step following their occurrence, for one step only.
- Calculations are based on situation at the beginning of the step
- A maximal subset of nonconflicting transactions and SRs is always executed

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Semantic Characteristics of Statecharts(3/3)

- **Time Scheme**
  - ***Synchronous time scheme***
    - **assumes that the system executes a single step every time unit.**
    - **modeling electronic digital systems, where execution is synchronized with clock signals,**
    - **external changes can occur between any two steps. The execution**
  - ***Asynchronous time scheme***
    - **allows several steps to take place within a single point in time.**
    - **In general, external changes can occur at any moment between steps and several such changes can occur simultaneously**

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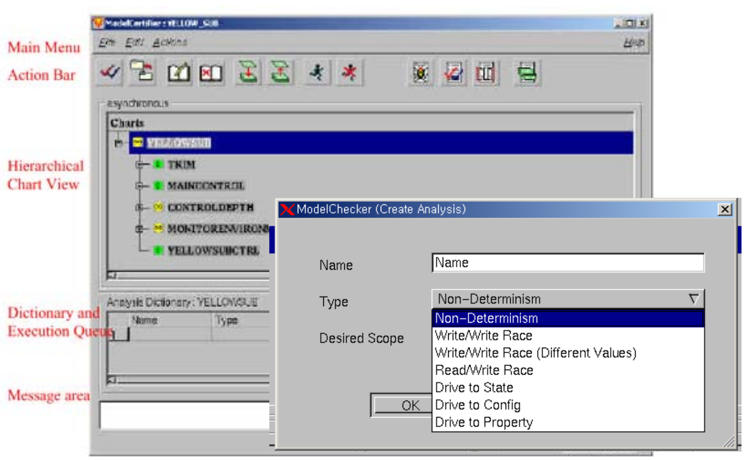
Verification in STATEMATE

- **Tools for validation**
  - Simulation
- **Tools for verification**
  - ModelChecker
  - ModelCertifier
    - which includes the whole functionality of ModelChecker.
- **Verification properties**
  - Non-Determinism
  - Write-Write Race
  - Write-Write Race (different values)
  - Read-Write Race
  - Drive-to State
  - Drive-to Configuration
  - **Drive-to Property**

ModelChecker



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SyncCharts

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Intro. to SyncCharts

- **Specification and design of large and complex reactive systems**
  - Telephone, Automobiles, Communication, SOC…
- **Provides for hierarchy, orthogonality, Synchrony hypothesis**

SyncCharts = FSM +
Depth(hierarchy) +
Concurrency(orthogonality) +
Broadcast-communication

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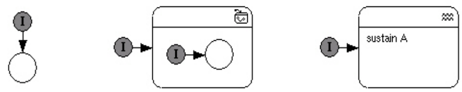
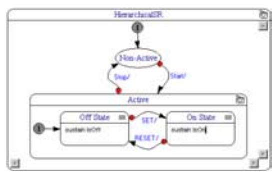
Syntax of SyncCharts(1/7)

- **Hierarchy**
  - State-levels
  - State : basic state, macro state



Graphic macro-state

Textual Macro-state



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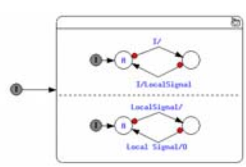
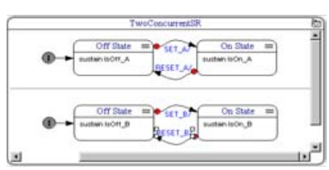
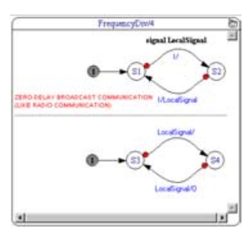
Syntax of SyncCharts (2/7)

- **Concurrency**
  - Synchronization and independence.

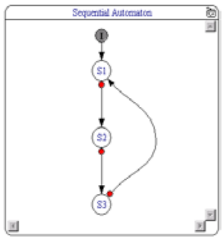




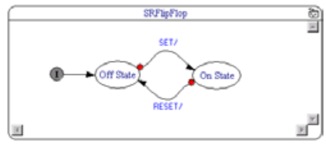


Syntax of SyncCharts(3/7)

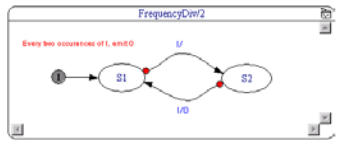
- Sequential Automata



- Trigger event

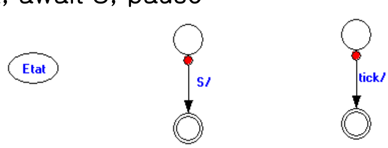


- Effect: signal emission

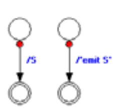


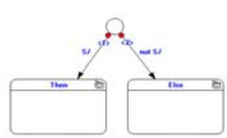
Syntax of SyncCharts(4/7)

- Halt points (remembering state)
  - Halt, await S, pause



- Signal emission and test
  - emit S, present S





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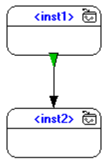
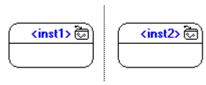
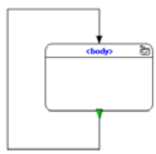
Syntax of SyncCharts(5/7)

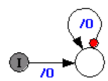
- **Control flow**
  - ; (sequence) and || (parallel)





  - loop, sustain, every





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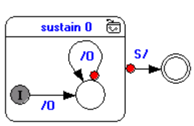
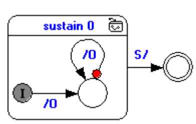
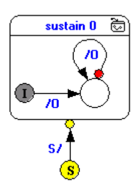
Syntax of SyncCharts(6/7)

- **Control flow(cont'd)**
  - abort, weak abort, suspend







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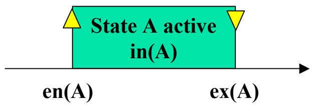
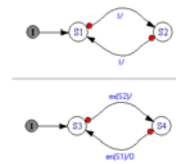
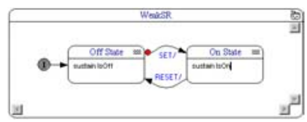
Syntax of SyncCharts(7/7)

- in()
  - when a state is being executed
- en(), ex()





- Strong vs weak abortion



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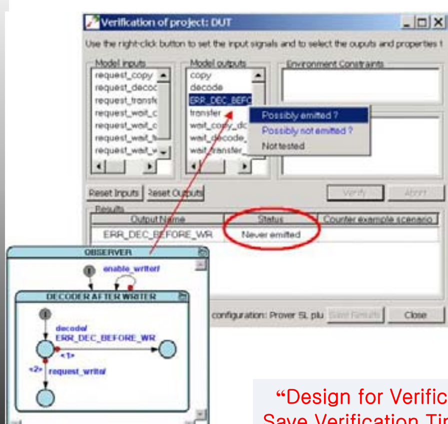
Verification of SyncCharts



- **Verification**
  - Model Checking
  - The Design Verifier using Model Checking validates the design by proving that the required system properties and assertions hold in all the possible cases.
    - *Assertions*
      - "a FIFO full never overflows" "
      - "Bus access can be granted to 1 only peripheral"

"Design for Verification and Save Verification Time & Effort With Esterel Studio"

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GCSR

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Intro. to GCSR

- **Features**
  - Graphical notations
  - Scalability
    - *Modular and hierarchical structures through nesting and modularity.*
  - Resource
  - Priority
  - Formal Semantics
  - Equivalence
    - *ACSR equivalence relation*
  - Executable

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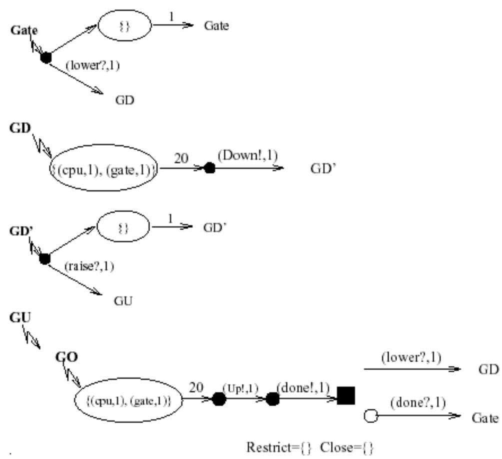
GCSR Language



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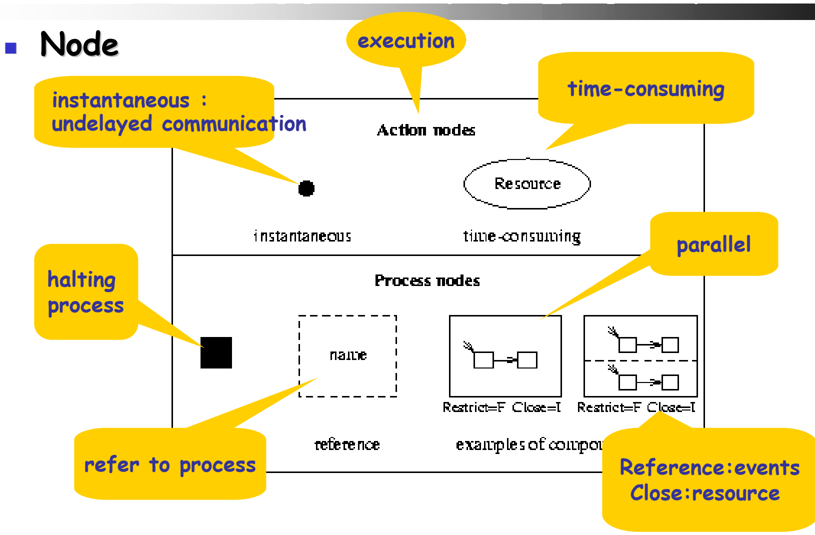
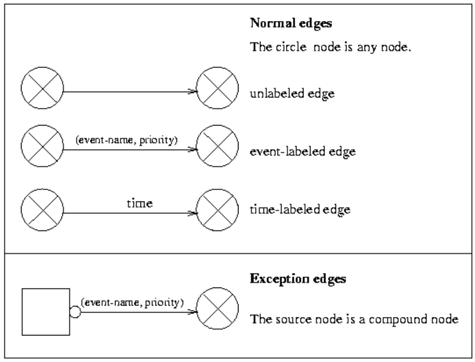
GCSR Syntax(1/2)

- Node



GCSR Syntax(2/2)



- **Edge**
  - Normal Edge
    - That is externally controlled by an interacting process
  - Exceptional Edge
    - That is triggered internally through voluntary release of control by raising an exception.

GCSR Process

- **GCSR process**
  - is a tuple <N,I,E,*L*,*R*>
    - *L* is a set of event names
    - R is a set of resource names
    - (N,E) is directed graph with initial node $I \subseteq N$
    - E is a set of labeled edges $\subseteq N \times L \times N$
    - L is set of labels $\subseteq \{\varepsilon\} \cup (L \times N) \cup (N \cup \infty)$
  - Hierarchical
    - hierarchical function : p
    - $p(n) = \{G_1, G_2, \ldots, G_k\}$
      - the processes $G_1, G_2, \ldots, G_k$ inside node n

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GCSR Semantics(1/3)

- **Informal Semantics**
  - a GCSR process represents a system.
    - A system can sequentially execute communication events or time and resource consuming actions
    - execution with instantaneous communication events
    - execution with resource and time consuming
    - execution with compound nodes

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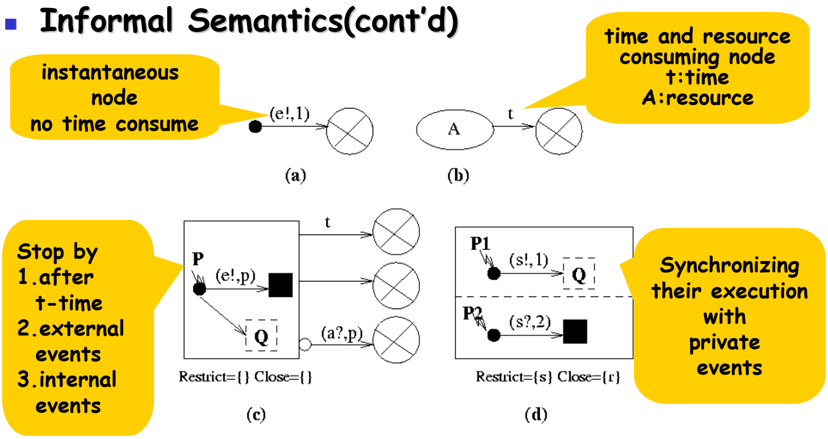
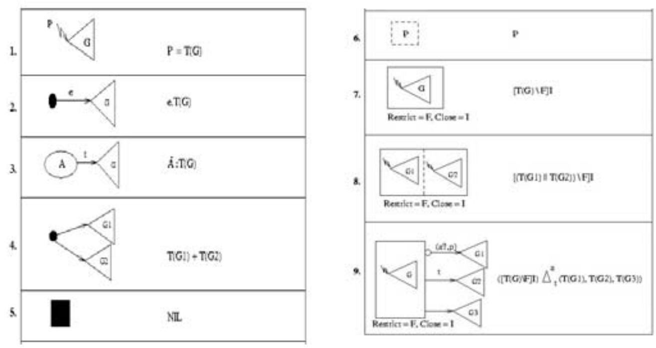
GCSR Semantics(2/3)

- **Informal Semantics(cont'd)**



GCSR Semantics(3/3)

- **Simple GCSR to ACSR process**
  - T represents translation form GCSR specification to ACSR processes



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Analysis Techniques

- **ACSR has operational semantics that make GCSR possible to execute a GCSR specification.**
- **This allows designers to test a GCSR specification for unintended behaviors before attempting to prove correctness.**
- **with algebraic semantics of GCSF, we can verify the strong and weak equivalence of two GCSR specification,**

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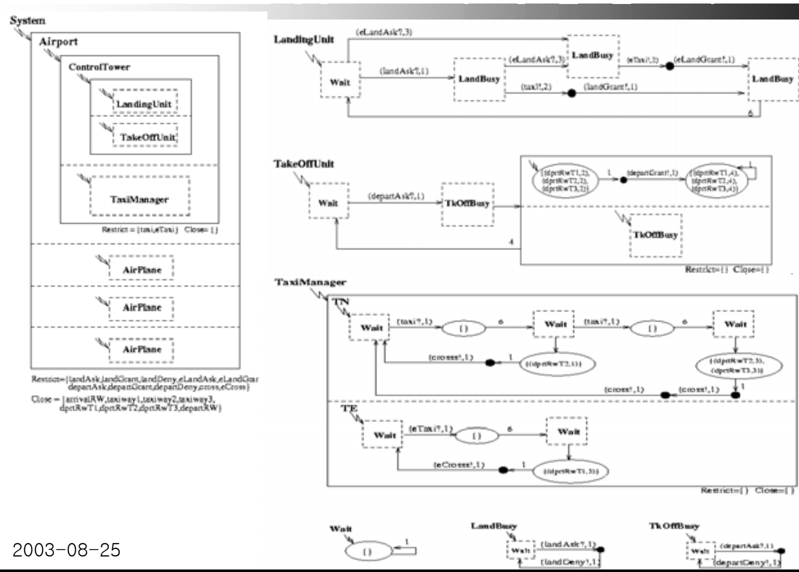
Example : Airport with taxi-way



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2003-08-25

Timed Automata using UPPAAL

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Intro. to UPPAAL(1/3)

- **Developed by Kim Larsen,Wang Yi and Paul Petterssoon ... in 1996**
- **Real-Time Verification and Validation Tools.**
  - RT-SPIN – Real-Time extensions to SPIN.
  - UPPAAL – Toolbox for validation and verification of real-time systems.
- **Real-Time Communication.**

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Intro. to UPPAAL (2/3)

- UPPAAL **consists of three main parts:**
  - a description language,
  - a simulator, and
  - a model checker.
- **The** description language **is a non-deterministic guarded command language with data types.**
  - describe a system as a *network of timed automata*
- **The** simulator **enables examination of *possible* dynamic executions of a system during the early modeling stages.**
- **The** model checker **exhaustively checks *all* possible states.**

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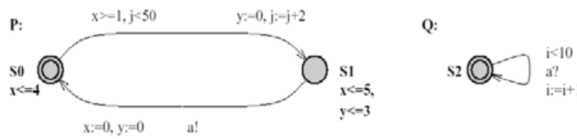
Intro. to UPPAAL(3/3)

UPPAAL Model =
Networks of Timed Automata



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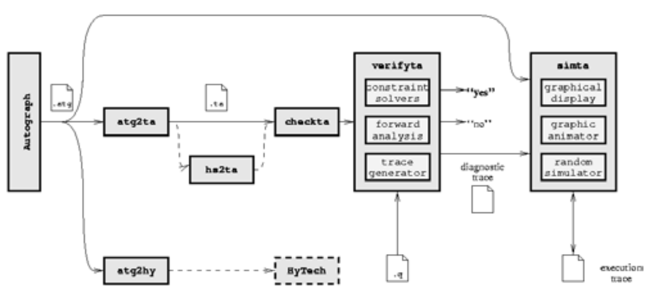
Intro. to UPPAAL

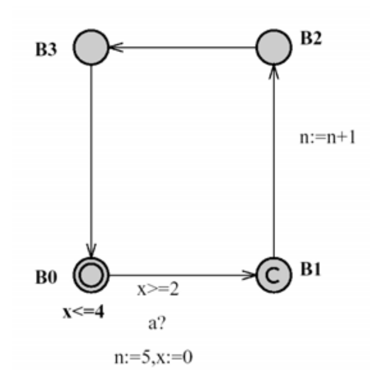


- checkta – **syntax checker**
- simta – **simulator**
- verifyta – **model checker**

Example (cont.)
(from UPPAAL in a Nutshell)

```
process B {
  state B0 { x<=4 }, B1, B2, B3;
  commit B1;
  init B0;
  trans B0 -> B1 {
    guard x>=2;
    sync a?;
    assign n:=5,x:=0;
  },
  B1 -> B2 {
    assign n:=n+1;
  },
  B2 -> B3 {
  }, B3 -> B0;
}

system A, B;
```



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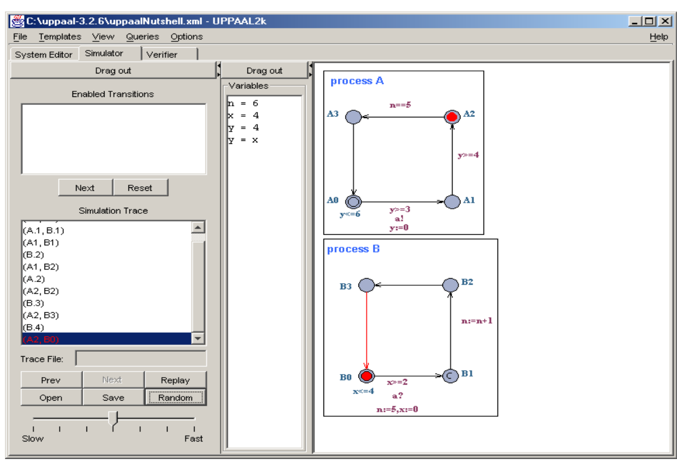
Example (cont.)



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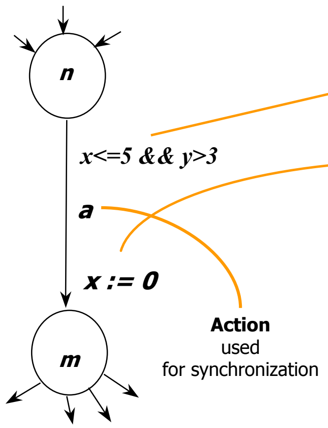
Timed Automata(1/2)



Clocks: *x, y*

Guard
Boolean combination of comp with integer bounds

Reset
Action perfomed on clocks

State
(***location*** , ***x***=v , ***y***=u) where v,u are in **R**

Transitions

(***n*** , ***x***=2.4 , ***y***=3.1415) —*a*→ (***m*** , ***x***=0 , ***y***=3.1415)

(***n*** , ***x***=2.4 , ***y***=3.1415) —*e(1.1)*→ (***n*** , ***x***=3.5 , ***y***=4.2415)

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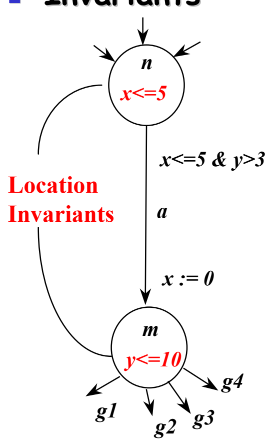
Timed Automata(2/2)

- **Invariants**



Clocks: *x, y*

Transitions

(*n* , *x*=2.4 , *y*=3.1415) ~~—*e(3.2)*→~~

(***n*** , ***x***=2.4 , ***y***=3.1415) —*e(1.1)*→ (***n*** , ***x***=3.5 , ***y***=4.2415)

Invariants ensure progress!!

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UPPAAL Specification Language

- **Temporal Logic**

```
A [] p  → (AG p)
E <> p → (EF p)
```

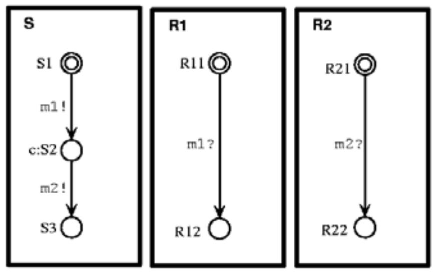
```
p::= a.l | gd | gc | p and p | p or p | not p |
     p imply p | ( p )
```


Syntax of UPPAAL(1/2)

- **Labels and Transitions**
  - The edges of the automata can be labeled with three different types of labels:
    - a <u>guard</u> expressing a condition on the values of clocks and integer variables that must be satisfied in order for the edge to be taken,
    - a <u>synchronization action</u> which is performed when the edge is taken
    - a <u>number of clock resets and assignments</u> to integer variables.
  - Nodes may be labeled with invariants
    - Conditions expressing constraints on the clock values in order for control to remain in a particular node

Syntax of UPPAAL(2/2)

- **Committed Locations**
  - A committed location must be left immediately.
    - ***A broadcast can be represented by two transitions with a committed state between sends.***



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Semantics of UPPAAL(1/5)

- **Transitions**
  - Delay transitions
  - Action transitions
- **The above tow types of transitions may be overruled by presence of urgent channels and committed locations in the following ways**
  - Urgent channels
  - Committed locations

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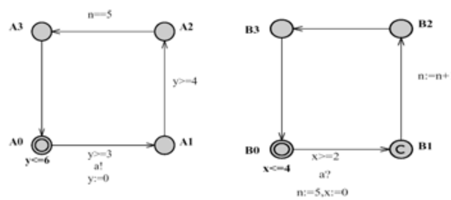
Semantics of UPPAAL(2/5)

- Delay transitions – **if none of the invariants of the nodes in the current state are violated, time may progress without making a transition; e.g., from ((A_0,B_0),x=0,y=0,n=0), time may elapse 3.5 units to ((A_0,B_0),x=3.5,y=3.5,n=0), but time cannot elapse 5 time units because that would violate the invariant on B_0.**



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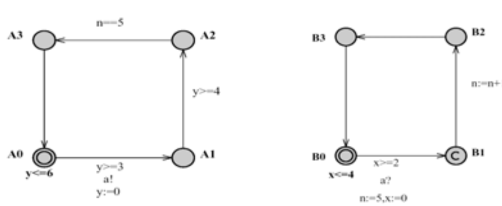
Semantics of UPPAAL(3/5)

- **Action transitions** – if two complementary edges of two different components are enabled in a state, then they can synchronize; also, if a component has an enabled internal edge, the edge can be taken without any synchronizaton; e.g., from ((A_0,B_0),x=0,y=0,n=0) the two components can synchronize to ((A_1,B_1),x=0,y=0,n=5).



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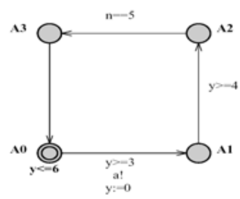
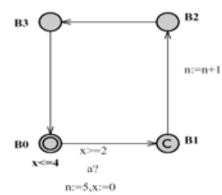
Semantics of UPPAAL(4/5)

- When two components can synchronize on an urgent channel, no further delay is allowed; e.g., if channel a is urgent, time could not elapse beyond 3, because in state $((A_0,B_0),x=3,y=3,n=0)$, synchronization on channel a is enabled.





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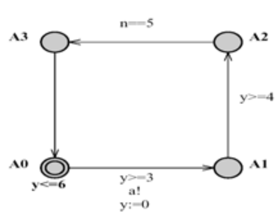
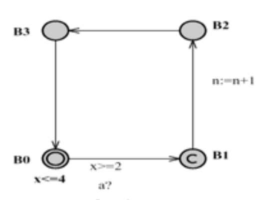
Semantics of UPPAAL(5/5)

- If one of the components is in a committed node, no delay is allowed to occur and any action transition must involve the component committed to continue; e.g., in state $((A_1,B_1),x=0,y=0,n=5)$, B_1 is committed, so the next state of the network is $((A_1,B_2),x=0,y=0,n=6)$.





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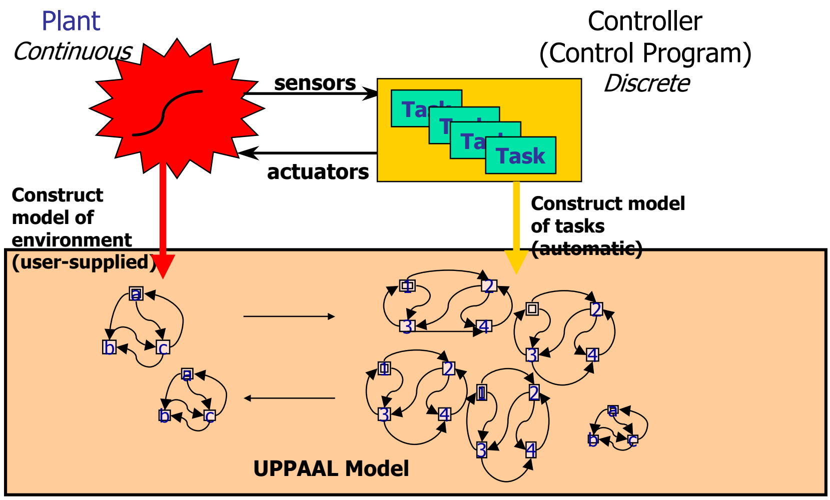
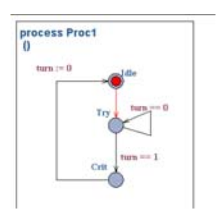
UPPAAL Model Construction

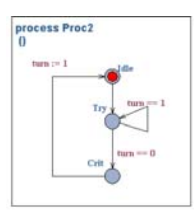


Translation to UPPAAL

```
P1 :: while True do
        T1 : wait(turn=1)
        C1 : turn:=0
        endwhile
||
P2 :: while True do
        T2 : wait(turn=0)
        C2 : turn:=1
        endwhile
```

Mutual Exclusion Program





Conclusion

- **Visual Formalism**
  - State-based specification and its verification
    - Statecharts
    - SyncCharts
    - GCSR
    - UPPAAL
  - Verification methods
    - Model Checking
    - Bi-simulation
- **Future…**
  - Real-time
    - Time, Resource, Priority, Concurrency
  - …You…