Statecharts

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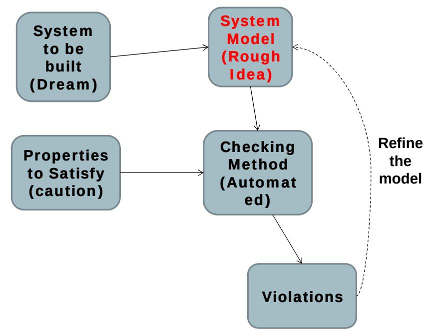
Warm up – the big picture



Background

- Finite state machines
  - Other variants
  - Model Reactive and transformational systems
- Statecharts is one of the simplest and most popular modeling formalism
  - Very intuitive, visual.
  - An illustration of how to model systems with statecharts will be shown via Rhapsody tool.
    - Also, tested in the first lab assignment.

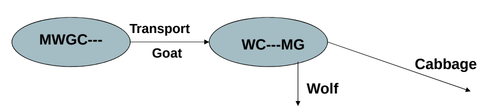
Readings

- Statecharts: A visual formalism for complex systems, by David Harel, Science of Computer Programming, 1987
- Executable object modeling with statecharts, by David Harel and Eran Gery, IEEE Computer, 1997
- Basic understanding of states/transitions is introduced first.

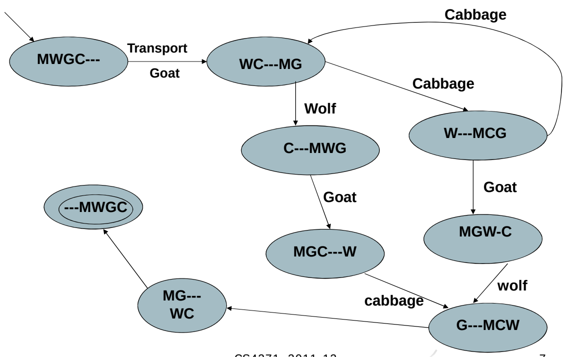
Introducing FSMs --- a puzzle

- A man with a goat, a wolf and a cabbage wants to cross a river.
- A boat can carry only 2 of the 4 entities.
- Wolf wants to eat the goat.
- Goat wants to eat the cabbage.
  - How to transport all the 4 entities ?
- Think of modeling the local state of each entity – on which side of the river?
  - A global state is a composition of these local states --- transitions of global states form FSM

State change



State change



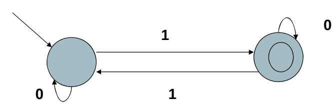
Modeling using FSMs

- A solution to our problem is a path from the initial state to a state where all 4 entities are on other side of river.
  - Notion of “termination” of the problem.
  - Shown as accepting states of FSMs
- Minor note:
  - Not all cycles in the FSM for this problem have been shown.

FSM --- Definition

- M = (S, S0, Σ, $\rightarrow$, F)
  - S is a set of states
  - S0 $\subseteq$ S is the set of initial states
  - $\rightarrow \subseteq S \times \Sigma \times S$ is the transition relation
  - F $\subseteq$ S is the set of final or accepting states
- The set of strings accepted by M or the language of M
  - L(M) = all strings which have a path from an initial state to an accepting state.
  - Using finite state machines for recognizing or distinguishing (infinite) set of (finite) strings.

FSM --- Example



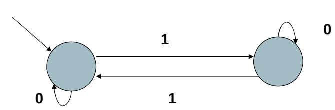
Accepts all binary strings with odd number of 1s

An infinite collection of finite strings

Transition Systems

- FSMs can accept infinite strings too, change accepting condition
  - An infinite string is accepted iff it visits at least one final state infinitely often.
- Transition systems go one step further where all states are accepting.
  - TS = (S, S0, Σ, $\rightarrow$)
    - No notion of terminating or accepting states
    - The alphabet Σ labeling the transitions is also optional.
    - The traces captured by a transition system are obtained by unrolling the graph from the initial state(s).

TS - Example



Traces captured by this transition system are

$(0^* 1)^* 0^\omega$

$(0^*1)^\omega$

Transformational Systems

- Conventional notion of a terminating program.
  - Takes in input.
  - Performs computation step.
  - Terminates after producing output.
- System behavior
  - Can be described as a transformation function over the input.
- What about controllers ?
  - In continuous interaction with the environment.

Reactive Systems

- Continuously interacts with its environment.
  - No notion of system termination.
- Interaction with environment is typically asynchronous.
- Often consists of a concurrent composition of processes.
  - Often, its response to environment needs to obey time constraints.

Reactive system behavior

- (Infinite) collection of infinite traces.
- Traces denote ongoing interaction with environment.
- Use state transition systems to describe behavior of a reactive system
  - Too much complexity
  - Many processes --- concurrency
  - Each process has many states --- hierarchy
  - What kind of inter-process communication?
- The language of Statecharts addresses these practical issues !!

Visual Formalisms

- Important/imperative at initial design stages.
- Vital for communication.
- Formal visual languages can help in:
  - Documentation
  - Initial analysis.
  - Developing correct-by-construction translation to more detailed (non-visual) descriptions.

Statecharts

- Statecharts =
  - FSMs +
  - Depth +
  - Orthogonality +
  - Structured transitions +
  - Broadcast communication
- Used in the Rhapsody tool.
- Included in UML 2.0 as state diagrams.

General Idea

- Statecharts
  - = FSM + many features to contain complexity.
- What does the FSM denote?
  - System response to external triggers.
  - States of the FSM = internal states of the system
  - Transitions of the FSM are labeled by such triggers.
    - An external trigger may in turn generate internal triggers which can also form the labels.
  - Traces of the FSM are sequence of transitions.
    - System response should stabilize eventually, waits for the next external trigger from environment.

Statecharts

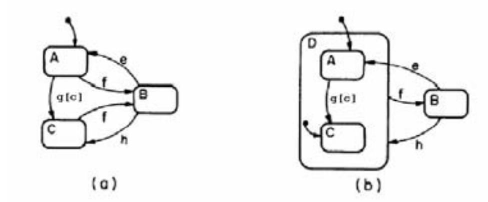
Depth:
- States can have internal structure.
- OR type states

Orthogonality
- Independent states
- Concurrency
- AND type states

Structured transitions
- Succinct descriptions of transition families.

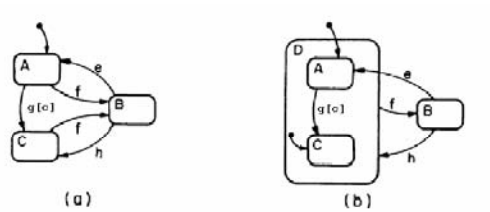
Broadcast communication
- Succinct descriptions of synchronizations

Depth : OR States



(b) is the statechart representation of the FSM (a).

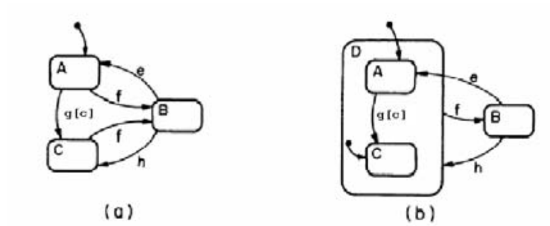
Depth : OR States



A and C are clustered into a superstate D

A and C are the internal exclusive-or components of the D state.

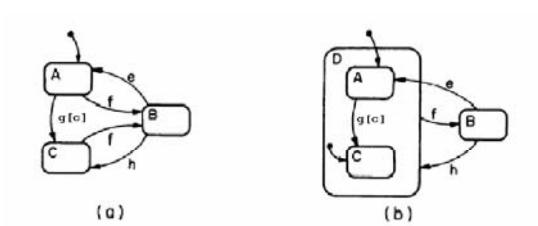
Depth : OR States



e, f : are trigger (external) events.

g [c]: g, a trigger event and c a condition

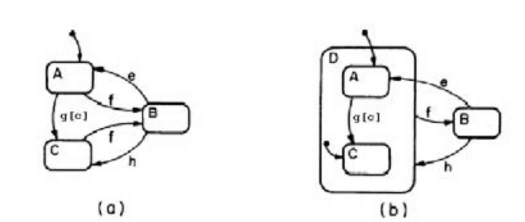
Depth : OR States



f is a transition from D to B.

From any D-state (A or C) there is an f-move to B

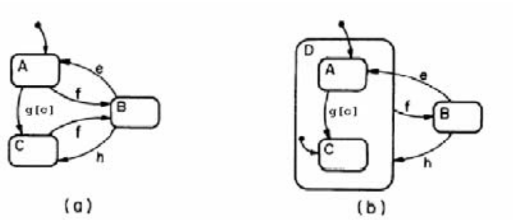
Depth : OR States



h is transition from B to D (A or C).

The actual state entered is the default entry state; the state C

Depth : OR States

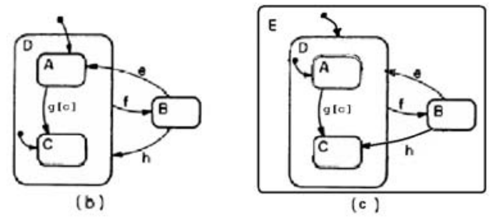


D is the initial state.

The actual initial state within D is not the default state C.

Instead, it is A.

Depth: OR States

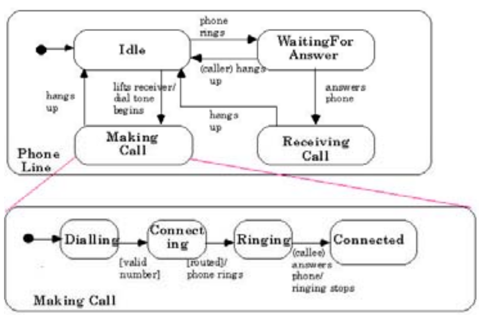


Which state will transition e yield in (b) and (c)?

Which state will transition h yield in (b) and (c)?

What's the default state for the superstate E in (c)? Hierarchically!

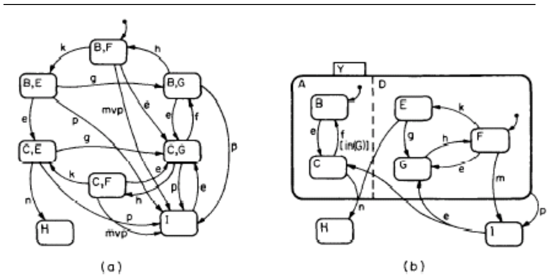
A Concrete Example: OR-chart



OR-State: in a nutshell

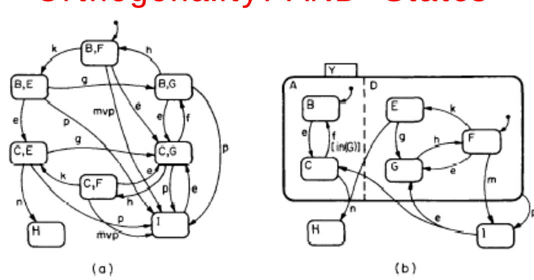
- An OR-state can contain other states as its internal substates (hierarchical internal structure);
- A super OR-state is active, if and only if one of its immediate substates is active (exclusive or);
- When the control enters a (super) OR-state, its default substate is entered and becomes active;
- When the control leaves a (super) OR-state, all its substates become inactive!
- More issues: history, priority, …

Orthogonality: AND States



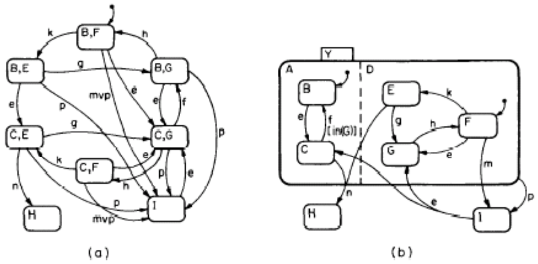
(b) is the statechart representation of the FSM (a).

Orthogonality: AND States



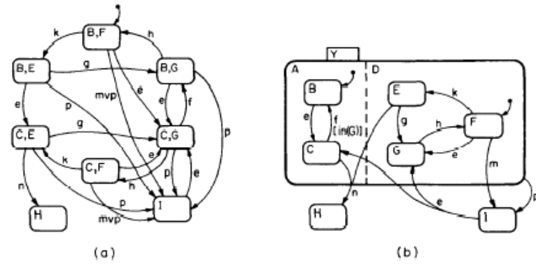
Y is an AND state.
It has two orthogonal components A and D.
A is an OR state with components B and C.
D is an OR state with components E, F and G.

Orthogonality: AND States



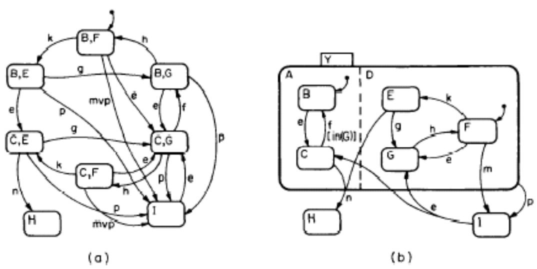
Y is an AND state.
It has two orthogonal components A and D.
a state of Y is composed of a state of A and a state of D
What is the default initial state of Y?

Orthogonality: AND States



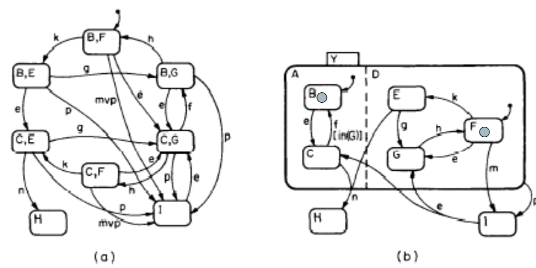
Y is an AND state.
It has two orthogonal components A and D.
a state of Y is composed of a state of A and a state of D
What is the default initial state of Y? (B,F)

Orthogonality: AND States



f belongs to only A.
e belongs to both A and D.
From (B,F) there is a simultaneous e-move to (C,G)

Orthogonality: AND States



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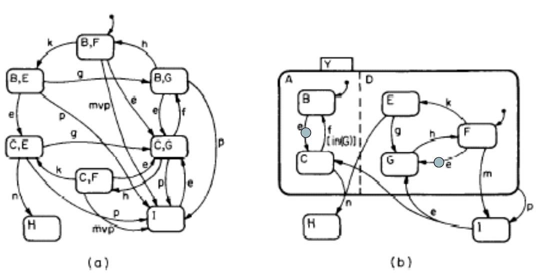

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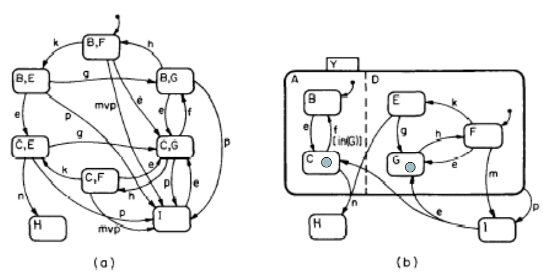

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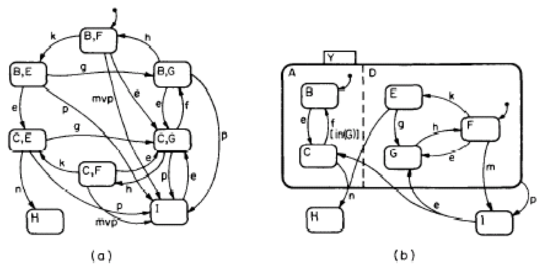
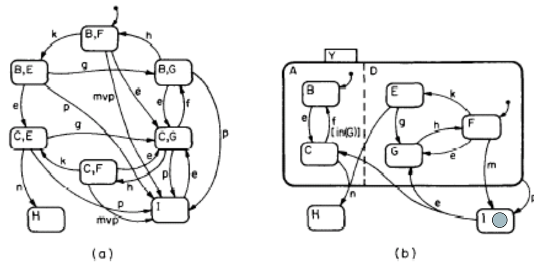
Orthogonality: AND States



(a) (b)

From every Y state (how many?) there is a p-move to I

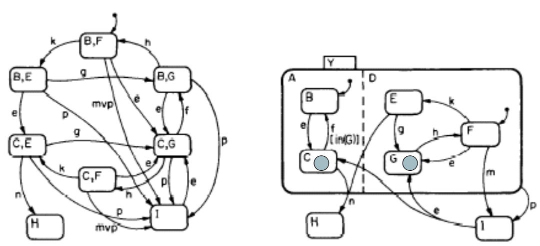
Orthogonality: AND States



(a) (b)

From every Y state (6!) there is a p-move to I
From I there is an e-move to the Y-state (?, ?)

Orthogonality: AND States

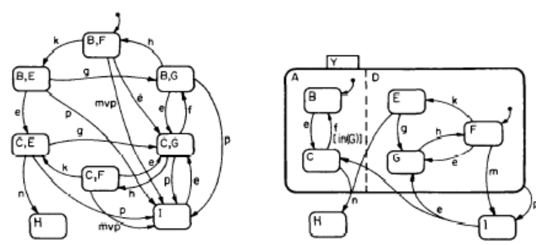


(a) (b)

From I there is an e-move to the Y-state (C, G)

What if there is an e-arrow from I to just the surface of Y

Orthogonality: AND States



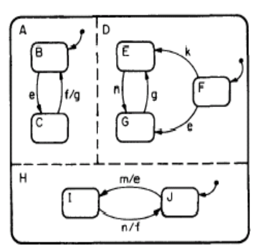
(a) (b)

For each (?, F) state there is an m-move to I
Note the [in G] condition attached to the f-move from C
(state reference!).

AND-state: in a nutshell

- An AND-state is composed of several independent (OR-)states that run in parallel (concurrency);
- An *active state* of an AND-state comprises a state of each concurrent component, i.e., $(s_1,s_2,\ldots,s_n)$;
- When the control enters (leaves) an AND-state, it simultaneously enters (leaves) all its components;
- An AND-state can even occur inside an OR-state (different from conventional programming languages)

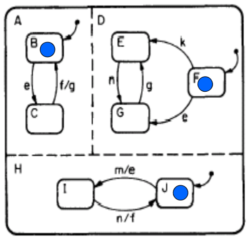
Broadcast Communication



A transition has a trigger and an action (output!)

But the output of a transition can be inputs for other orthogonal components!

Broadcast Communication

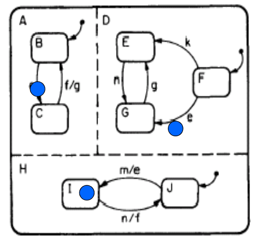


Start configuration (B, F, J)

m/e: m is the trigger event, while e is the action (output!)

Suppose m (external event) occurs.

Broadcast Communication

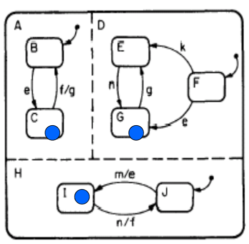


Start configuration (B, F, J)

Suppose m (external event) occurs.

H goes to I from J ; e-moves are enabled in A and D

Broadcast Communication

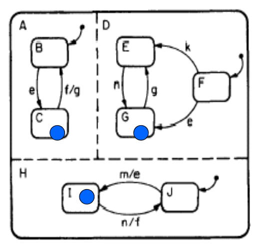


Start configuration (B, F, J)

m occurs

Final configuration (C, G, I)

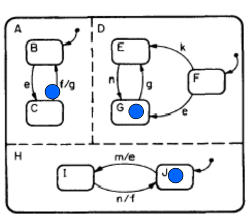
Broadcast Communication



Suppose event n comes,

What happen now?

Broadcast Communication

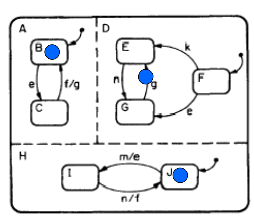


Now suppose event n comes,

What happen? Transition $I \xrightarrow{n/f} J$ is fired, f is generated,

which fires transition $C \xrightarrow{f/g} B$

Broadcast Communication

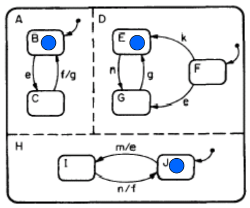


Now suppose event n comes,

What happen? Transition $I \xrightarrow{n/f} J$ is fired, f is generated,

which fires transition $C \xrightarrow{f/g} B$, which again fires $G \xrightarrow{g} E$

Broadcast Communication



Now suppose event n comes,

Transition $I \xrightarrow{n/f} J$ is fired, f is generated,

which fires transition $C \xrightarrow{f/g} B$, which again fires $G \xrightarrow{g} E$

Finally yielding (B,E,J)

What are the triggers/actions

- Method call
  - Method_name(parameters)
- Or, Event
  - Event_name(parameters)
- Is there a difference?
  - Lots, in terms of semantics
  - A method call involves a transfer of control
    - If there are nested method calls, they can cause further transfer of control
  - An event will be lodged in a system queue
    - It will be removed by the recipient later.

Events and Method calls

- Event based communication
  - Inherently asynchronous
    - Designer does not worry about controlling all interaction sequences (this is taken care of by the system queue)
- Method call based communication
  - Synchronous, involving transfer of control
  - Involves close control by the designer over interaction sequences ---
    - getting closer to code level

Most General form of ...

- ... annotation for a transition
  - Trigger[condition]/Action
- Trigger is event expression or method invocation
- Condition is like a branch condition on data variables
- Action is a program
  - Sequence of event generation or method invocation or even code in a programming language.

Summary

- Practical Use of Statecharts in Modeling Object-based systems
  - Use statecharts to describe behavior of classes (of active objects)
  - Class Associations given by class diagrams.
  - Contains code in the actions for realistic designs
- A realistic approach for modeling (distributed) embedded controllers.