Statemate Course

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Introduction to Statecharts

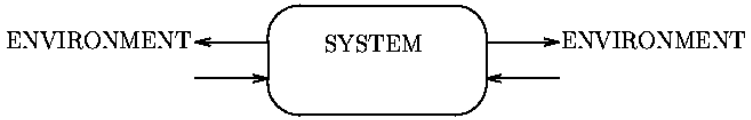
Everything you wanted to know about Statecharts
but were afraid to ask

Abstract: The notion of a reactive system and the language Statecharts are introduced. The rationale behind the design decisions of Statecharts is explained in relation to the specific nature of reactive systems.

Literature: Introduction to Design Choices in the Semantics of Statecharts, C. Huizing, W.-P. de Roever, Information Processing Letters 37, p. 205-213, 1991

What is a system?

A composed and relative independent whole that can exchange (material, energy, information) with its environment.



The two essential elements in this definition are:

1. group of components, that form a connected whole
2. the exchange with its environment.

How to Characterize Systems?

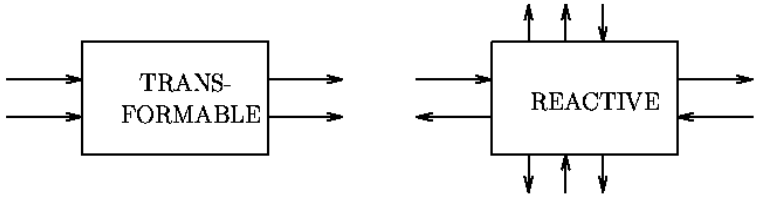
The systems are often divided in two categories that make distinction between more simple and more difficult systems.
Examples of this separation are:

- sequential versus parallel,
- central versus distributed,
- deterministic versus nondeterministic,
- terminating versus nonterminating.

Another Separation

There is another separation, namely:

- **transformational** and
- **reactive systems**.



Transformational systems

are described by the relation between initial and corresponding final states; they have a linear structure, because only the initial and corresponding final states are of interest.

Examples include: sorting algorithms, compilers, and other algorithms computing a function as discussed in your data structures and complexity of algorithms course.

Reactive systems

do not compute a function, but are in continuous **interaction** with their environment.

Examples: your tv set, digital watches, chips, interactive software systems, game programs s.a. trackman, monkey island, tomb raider, and other interactive computer games, but also one's heart monitor at an intensive care unit.

Why use Formal Methods?

- in the formalization process ambiguities, omissions and contradictions can be found in the informal formulation of the problem,
- the formal model can be proven correct with mathematical methods,
- a formal specified system can be analyzed to have or to have not some wanted properties,
- a formal verified subsystem can be embedded in a greater system with more confidence,
- the formal model leads to (partly) automated development methods and tools like simulators,
- several designs can be compared with each other.

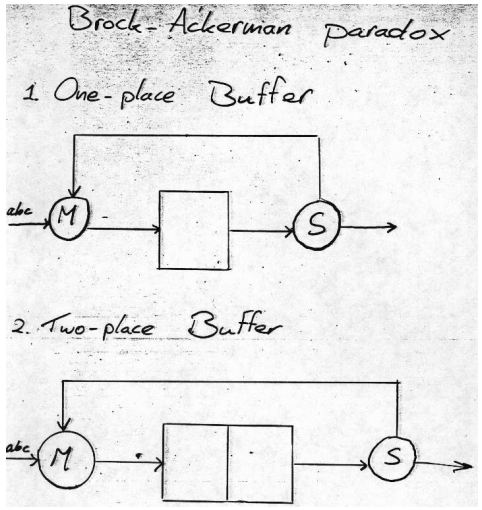
Transformational/Reactive Systems

- Transformational systems are well-studied; for their programming and analysis many good languages and theories exist.
- We explain why the language Statecharts is a good candidate for **specifying** and **programming** reactive systems.

Why not use transformational techniques?

- If transformational systems are so well studied, why doesn't one consider a reactive system as a transformational one?
  Simply say that a reactive system transforms a **sequence** of inputs to a sequence of outputs.
- This doesn't work, because of "feedback", as illustrated by the **Brock-Ackermann** paradox.
- Consider two systems, a one-place buffer and a two-place buffer. If you consider these transformationally, they display the same initial-final state behavior.

Brock-Ackermann paradox



in: $abc\ldots$
out: 1. e.g. $abac\ldots$
2. e.g. $abca\ldots$
not $abac\ldots$

Conclusion

If the output of these systems is fed back, and merged with their input they behave differently.

> The relative order of output events relative to the input events needs to be specified, in order to characterize the semantics of a system with interaction with its environment through feedback.

(One needs to know when an output is produced)

Initial/Final State Behavior

Transformational systems have a linear structure, and so have the conventional languages for specifying and programming them. What one describes is how a final state is produced from an initial one. **The relative time when intermediate states are computed is not important**, and neither is their identity as long as the corresponding final state is known!

Reactive Behavior

- For reactive systems this is completely different:
  - The "moment" a new input arrives is relevant to the behavior of the system $\Longrightarrow$
  - The internal state of the system at the time of input is important for the systems reaction.
  - Reactive systems may not even have a final state!
- So, in reactive systems **there is no main sequential flow of control** (as in transformational systems) and **statements can have several entry and exit points**.

Finite State Machines

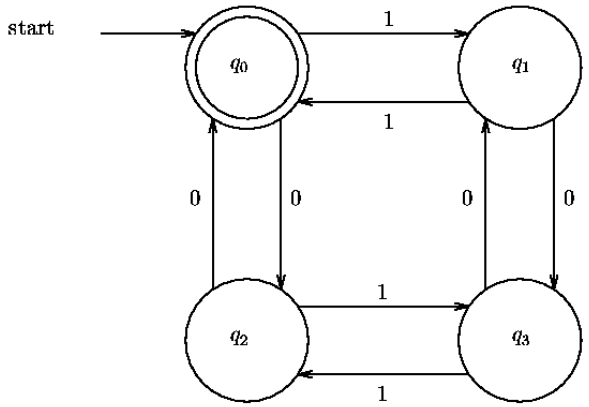
Finite Automata

Formally a *finite automaton* is defined as a five tuple $(Q, \Sigma, \delta, q_0, F)$ where

Q	is a finite set of states,
Σ	is the input alphabet,
$q_0 \in Q$	is the begin state,
$F \subseteq Q$	is the set of final states,
$\delta : Q \times \Sigma \rightarrow Q$	is the transition function.

The transition function gives for every state q and every input symbol a the new state $\delta(q, a)$ that arises as reaction on the execution of a in state q.

State Diagram



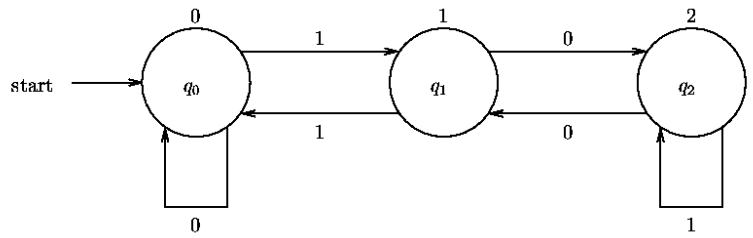
For each state, the possible reactions to input that arrives in that state is specified by a transition to other states.

Extensions

A restriction of these kind of automata as defined above is the fact that they have an input alphabet but not an output alphabet. There are two ways to extend the above model with output: output can be associated with a state (a so called Moore machine) or with a transition (a so called Mealy machine). These are formally defined as follows.

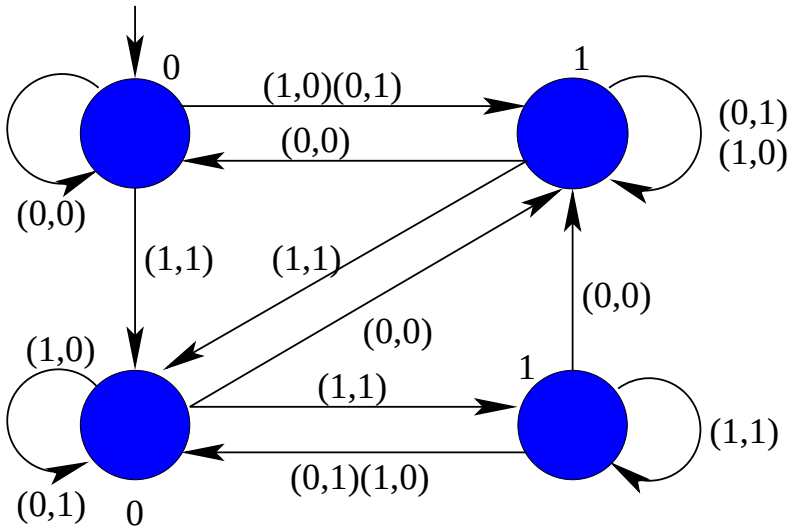
- A $Moore\ machine$ is a 6-tuple $(Q, \Sigma, \Delta, \delta, \lambda, q_0)$ where Q, Σ, δ, q_0 are the same as in the definition of the finite automaton,
  Δ is the $output\ alphabet$ and
  $\delta : Q \to \Delta$ is the $output\ function$.
- A $Mealy\ machine$ is also a 6-tuple $(Q, \Sigma, \Delta, \delta, \lambda, q_0)$ but now λ is a function from $Q \times \Sigma$ to Δ.

Example: Moore Machine

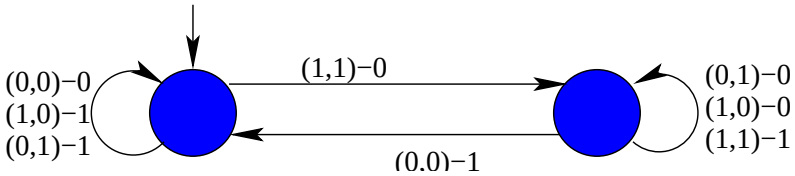


For a Moore machine λ the output is thus associated with every state, while for a Mealy machine $\lambda(q, a)$ gives the output associated with the transition of state q on input a.

Serial Addition: Moore Machine



Serial Addition: Mealy Machine

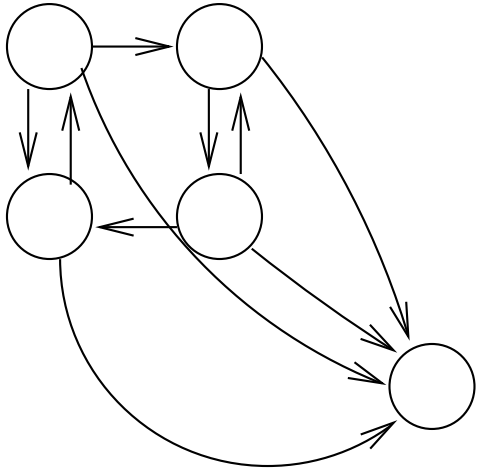


Disadvantages

- **They have no structure**. There is no strategy for their top-down or bottom-up development.
- state-transition diagrams are “flat”, i.e., without a natural notion of depth, hierarchy or modularity,
- state-transition diagrams are uneconomical concerning their transitions:think for instance of a high-level interrupt

Interrupt Transition

They are not economical w.r.t. transitions, when one event has all transitions as a starting point as in case of interrupts:



Interrupt state

Disadvantages (cont’d)

- concerning the states state-transition diagrams are even very uneconomical: exponential blow-up
- They are not economical w.r.t. **parallel composition**: **Exponential growth** in the number of states when composed in parallel.
- the nature of state-transition diagrams is inherently sequential and so parallelism can‘t be represented in a natural way.

Statecharts

We need a formalism for the hierarchical development and refinement of Mealy machines.
This is provided by Statecharts, invented by David Harel.

Statecharts display **hierarchy** and **structure**, and enable hierarchical development.

Statecharts

Hierarchy and Structure

The concepts of hierarchy and structure in Statecharts are introduced using a quite familiar example of a reactive system: that of a **television set with remote control**.

First concept: Hierarchy

Hierarchy or depth in states, and interrupts. This is achieved by drawing states as boxes that contain other boxes as sub-states.

- The television set can be in two states: **on** and **standby**. Switching between them is done by pushing the **on** and **off** buttons, generating the **on** and **off** events:

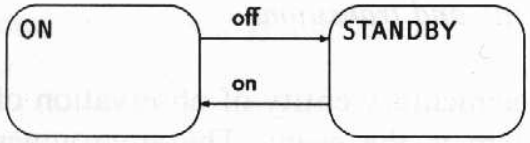


Fig. 2.

Zooming into ON

In state **on** the tv set can be in two sub-states: **normal** and **videotext**:

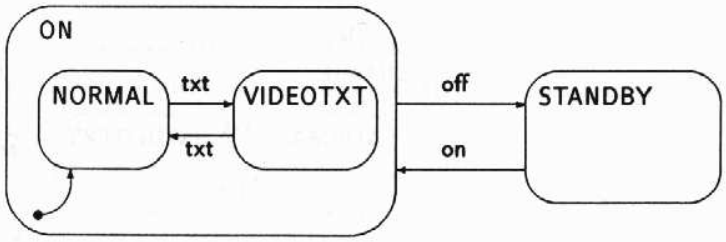


Fig. 3.

The $\longrightarrow$ arrow leading to **normal** specifies which sub-state should be entered when the higher level state**on** is entered, namely **normal**.

Superstates

When in **on** an event **off** is generated, this acts like an interrupt and state **on** (incl. all its sub-states) is left, and control switches to state **standby**. In this way interrupts are handled without cluttering the picture with arrows.

Second concept: Orthogonality

- Two independent components can be put together into an **AND-state**, separated by a dotted line

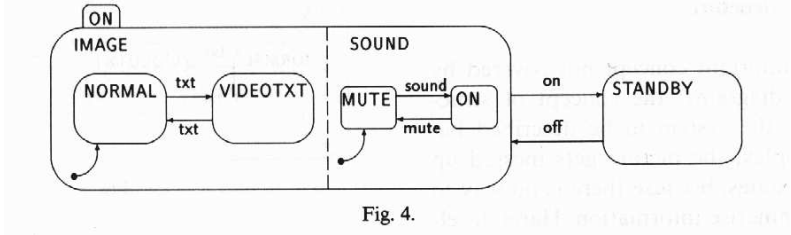


Fig. 4.

- Being in an AND-state means being in all of its immediate sub-states **at the same time**. This prevents the exponential blow-up familiar from composing FSMs in parallel.

Third concept: Broadcast

In our case we split state **normal** in two orthogonal components **channel**, for selecting channels, and **sm** for switching to mute:

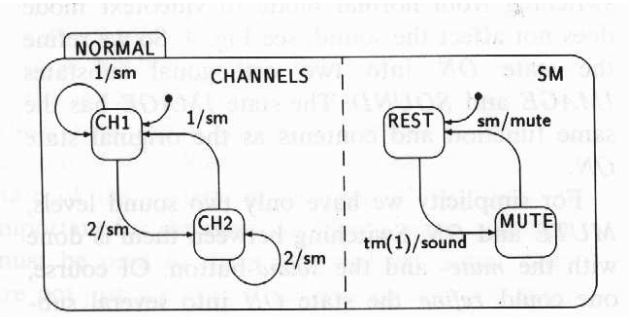


Fig. 5.

Behavior

- When a channel button (1 or 2, for simplicity) is pressed, one switches to that channel and the internal event **sm** is generated. This causes the event **mute** by a transition in **sm** to state **mute**, and the sound will be turned off.
- After **one second** the event **sound** is generated to turn the sound on, again. This is done by the special **time-out** event **tm(1)**.

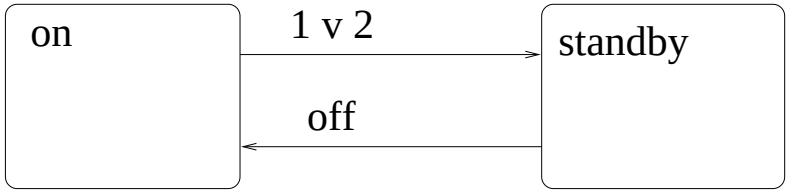
Actions and Transitions

Thus one sees that orthogonal components can communicate by generating events which are broadcast, and that this can be done in a time-dependent manner: introducing the **generation of events** $e/a_1; \ldots ; a_n$ and **time-out events tm(1), ...**

In general the label of a transition consists of two parts: a **trigger** that determines if and when a transition will be taken, and an **action** that is performed when a transition is taken. This action is the generation of a **set of events**.

Fourth concept: Compound events

When in state **standby**, dependent on whether one presses button 1 or 2 one makes sure to switch to states **ch1** or **ch2** in **on**. This is indicated as follows:



Transition Labels

- In general one can label transitions by **compound events** s.a. $(\neg a \wedge b) \vee c, a \wedge b, c \vee d, \neg a$, etc

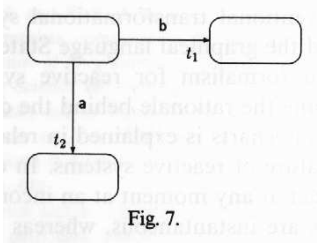


Fig. 7.

- E.g., in: a can be replaced by $a \wedge \neg b$ to express priority of event b over event a.

Summa Summarum

In a nutshell, one may say with David Harel:

$$\begin{aligned} \text{Statecharts} &= \text{Mealy Machines} \\ &+ \text{depth} \\ &+ \text{orthogonality} \\ &+ \text{broadcast} \\ &+ \text{data} \end{aligned}$$