Early design phases

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(slides are based on Peter Marwedel)
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# Models of computation considered in this course

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<th>Shared memory</th>
<th>Message passing</th>
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<td>C, C++, Java</td>
<td>C, C++, Java with libraries CSP, ADA</td>
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Capturing the requirements as text

- In the very early phases of some design project, only descriptions of the system under design (SUD) in a natural language such as English or Japanese exist.

- Expectations for tools:
  - Machine-readable
  - Version management
  - Dependency analysis
Use cases

- Use cases describe possible applications of the SUD
- Included in UML (Unified Modeling Language)
- Example: Answering machine

- Neither a precisely specified model of the computations nor a precisely specified model of the communication
(Message) Sequence charts

- Explicitly indicate exchange of information
- One dimension (usually vertical dimension) reflects time
- The other reflects distribution in space

Example:

![Sequence chart diagram]

- Included in UML
- Earlier called Message Sequence Charts, now mostly called Sequence Charts
Example (2)
Application: In-Car Navigation System

Car radio with navigation system
User interface needs to be responsive
Traffic messages (TMC) must be processed in a timely way
Several applications may execute concurrently
System Overview

![System Overview Diagram]

- **MMI**
- **Communication**
- **NAV**
- **RAD**
- **DB**
Use case: Change Audio Volume
Use case: Change Audio Volume

Communication Resource Demand

Execution time estimates
- HandleKeyPress() 1E5 instructions
- AdjustVolume() 1E5 instructions
- UpdateScreen() 5E5 instructions

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Time/distance diagrams as a special case

No distinction between accidental overlap and synchronization
Time/distance diagrams as a special case
UML: Timing diagrams

Can be used to show the change of the state of an object over time.

Summary

- Support for early design phases
  - Text
  - Use cases
  - (Message) sequence charts
StateCharts and StateMates

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StateCharts

Classical automata not useful for complex systems (complex graphs cannot be understood by humans).

Introduction of hierarchy StateCharts [Harel, 1987]
StateChart = the only unused combination of "flow" or "state" with "diagram" or "chart"

Used here as a (prominent) example of a model of computation based on shared memory communication.

appropriate only for local (non-distributed) systems
Introducing hierarchy

FSM will be in exactly one of the substates of S if S is active (either in A or in B or ..)
Definitions

- Current states of FSMs are also called **active** states.
- States which are not composed of other states are called **basic states**.
- States containing other states are called **super-states**.
- Super-states $S$ are called **OR-super-states**, if exactly one of the sub-states of $S$ is active whenever $S$ is active.
Default state mechanism

Try to hide internal structure from outside world!

Default state

Filled circle indicates sub-state entered whenever super-state is entered.

Not a state by itself!
History mechanism

For input $m$, $S$ enters the state it was in before $S$ was left (can be $A$, $B$, $C$, $D$, or $E$).

If $S$ is entered for the first time, the default mechanism applies.
Combining history and default state mechanism

History and default mechanisms can be used hierarchically.
Concurrent ways of describing concurrency req.

**AND-super-states**: FSM is in all (immediate) sub-states of a super-state;

Example:

```
answer-thing-machine
```

```
\begin{center}
\begin{tikzpicture}
\node[state] (Lwait) at (0,0) {Lwait};
\node[state] (Lproc) at (2,0) {Lproc};
\node[state] (Kwait) at (4,0) {Kwait};
\node[state] (Kproc) at (6,0) {Kproc};
\node[state, initial] (off) at (3,3) {off};
\node (line-monitoring) at (1,-1) {line-monitoring};
\node (key-monitoring) at (5,-1) {key-monitoring};
\node (on) at (1,1) {on};
\node (key-on) at (5,2) {key-on};
\node (key-off) at (5,-2) {key-off};
\node (excl) at (6,0) {excl. on/off};
\node (ring) at (1,1) {ring};
\node (hangup) at (1,-2) {hangup (caller)};
\node (key-pressed) at (5,1) {key pressed};
\node (done) at (5,-2) {done};
\draw (Lwait) edge[->] node[swap] {ring} (Lproc);
\draw (Lproc) edge[->] node[swap] {hangup (caller)} (Lwait);
\draw (Kwait) edge[->] node[swap] {key pressed} (Kproc);
\draw (off) edge[->] node[swap] {key-pressed} (Kwait);
\draw (off) edge[->] node[swap] {key-off} (Lwait);
\draw (Kwait) edge[->] node[swap] {done} (off);
\draw (off) edge[->] node[swap] {key-on} (Kproc);
\end{tikzpicture}
\end{center}
```
Types of states

In StateCharts, states are either

- basic states, or
- AND-super-states, or
- OR-super-states.
Timers

Since time needs to be modeled in embedded & cyber-physical systems, timers need to be modeled. In StateCharts, special edges can be used for timeouts.

If event a does not happen while the system is in the left state for 20 ms, a timeout will take place.
Using timers in an answering machine
General form of edge labels

Events:
- Exist only until the next evaluation of the model
- Can be either internally or externally generated

Conditions:
- Refer to values of variables that keep their value until they are reassigned

Reactions:
- Can either be assignments for variables
- or creation of events

Example:
- $service-off \ [\text{not in } Lproc] \ / \ service:=0$
The StateCharts simulation phases
(StateMate Semantics)

How are edge labels evaluated?

Three phases:

1. Effect of external changes on events and conditions is evaluated,
2. The set of transitions to be made in the current step and right hand sides of assignments are computed,
3. Transitions become effective, variables obtain new values.

Separation into phases 2 and 3 enables a resulting unique ("determinate") behavior.
Example

In phase 2, variables $a$ and $b$ are assigned to temporary variables:

\[
\begin{align*}
a' &:= b, \\
b' &:= a;
\end{align*}
\]

In phase 3, these are assigned to $a$ and $b$.

\[
\begin{align*}
a := a', \\
b := b';
\end{align*}
\]

As a result, variables $a$ and $b$ are swapped.
Example (2)

In a single phase environment, executing the left state first would assign the old value of $b$ (=0) to $a$ and $b$:

$$a := 0, b := 0;$$

Executing the right state first would assign the old value of $a$ (=1) to $a$ and $b$.

$$b := 1, a := 1;$$

The result would depend on the execution order.
Reflects model of clocked hardware

In an actual clocked (synchronous) hardware system, both registers would be swapped as well.

Same separation into phases found in other languages as well, especially those that are intended to model hardware.
Steps

Execution of a StateMate model consists of a sequence of (status, step) pairs

\[
\text{Status} = \text{values of all variables} + \text{set of events} + \text{current time} \\
\text{Step} = \text{execution of the three phases (StateMate semantics)}
\]

Other implementations of StateCharts do not have these 3 phases (and hence could lead to different results)!
Lifetime of events

Events live until the step following the one in which they are generated ("one shot-events").
Other semantics

Several other specification languages for hierarchical state machines (UML, dave, …) do not include the three simulation phases.

These correspond more to a SW point of view with no synchronous clocks.

Some systems allow turning the multi-phased simulation on and off.
Broadcast mechanism

Values of variables are visible to all parts of the StateChart model. New values become effective in phase 3 of the current step and are obtained by all parts of the model in the following step.

StateCharts implicitly assumes a broadcast mechanism for variables (→ implicit shared memory communication –other implementations would be very inefficient -).

StateCharts is appropriate for local control systems (😊), but not for distributed applications for which updating variables might take some time (😔).
Determinate vs. deterministic

- Kahn (1974) calls a system **determinate** if we will always obtain the same result for a fixed set (and timing) of inputs.

- Others call this property **deterministic**

  However, this term has several meanings:
  - Non-deterministic finite state machines
  - Non-deterministic operators
    (e.g. + with non-deterministic result in low order bits)
  - Behavior not known before run-time
    (unknown input results in non-determinism)
  - In the sense of determinate as used by Kahn

In order to avoid confusion, we use the term “determinate“ in this course.
Conflicts

Techniques for resolving these conflicts wanted
StateCharts determinate or not?

Must all simulators return the same result for a given input?

- Separation into 3 phases a required condition

- Semantics $\neq$ StateMate semantics may be non-determinate

Potential other sources of non-determinate behavior:

- Choice between conflicting transitions resolved arbitrarily: Tools typically issue a warning if such a situation could exist

$\Rightarrow$ Determinate behavior for StateMate semantics if transition conflicts are resolved and no other sources of undefined behavior exist
Evaluation of StateCharts (1)

Pros (👍):

- Hierarchy allows arbitrary nesting of AND- and OR-super states.
- (StateMate-) Semantics defined in a follow-up paper to original paper.
- Large number of commercial simulation tools available (StateMate, StateFlow, BetterState, ...)
- Available “back-ends“ translate StateCharts into SW or HW languages, thus enabling software or hardware implementations.
Backups

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Use case 3: Receive TMC Messages

![Diagram of communication system with MMI, Communication, NAV, DB, and RAD components]
Use case 3: Receive TMC Messages

- RadioStation
- Radio
- Navigation
- MMI
- User

Execution time estimates:
- HandleTMC(): 1E6 instructions
- DecodeTMC(): 5E6 instructions
- UpdateScreen(): 5E5 instructions

300 messages per 15 minutes
32 bytes each
uniform distribution

300 messages per 15 minutes
64 bytes each

30 messages per 15 minutes
64 bytes each

NoticeVisualChange()
Life Sequence Charts* (LSCs)

Key problems observed with standard MSCs:
During the design process, MSC are initially interpreted as
“what could happen”
(existential interpretation, still allowing other behaviors).
Later, they are frequently assumed to describe
“what must happen”
(referring to what happens in the implementation).

Extensions for LSCs (1)

Extension 1:
Introduction of **pre-charts**: Pre-charts describe conditions that must hold for the main chart to apply.

Example:
## Extension 2: Mandatory vs. provisional behavior

<table>
<thead>
<tr>
<th>Level</th>
<th>Mandatory (solid lines)</th>
<th>Provisional (dashed lines)</th>
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<tr>
<td>Chart</td>
<td>All runs of the system satisfy the chart</td>
<td>At least one run of the system satisfies the chart</td>
</tr>
<tr>
<td>Location</td>
<td>Instance must move beyond location/time</td>
<td>Instance run need not move beyond loc/time</td>
</tr>
<tr>
<td>Message</td>
<td>If message is sent, it will be received</td>
<td>Receipt of message is not guaranteed</td>
</tr>
<tr>
<td>Condition</td>
<td>Condition must be met; otherwise abort</td>
<td>If condition is not met, exit subchart</td>
</tr>
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</table>
(Message) Sequence Charts

**PROs:**
- Appropriate for visualizing schedules,
- Proven method for representing schedules in transportation.

**CONS:**
- describes just one case, no timing tolerances: "What does an MSC specification mean: does it describe all behaviors of a system, or does it describe a set of sample behaviors of a system?"