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The contribution is partially funded by the EFRE (European fund for regional development) of the European Union.

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TTCN-3 User Conference 2009
3 – 5 June 2009 - ETSI, Sophia Antipolis, France

Testing Embedded Systems in the Automotive Industry with TTCN-3

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Test Specification Technology and Methodology for Embedded Real Time Systems in the Automobile

- Testing discrete and continuous real time systems with TTCN-3 embedded.
- Test support for the entire integration process.
- Exchange of test definitions between
  - OEM and supplier
  - various test- and simulation platforms e.g. Model in the Loop (MIL) platforms, Software in the Loop (SIL) platforms, and Hardware in the Loop (HIL) platforms
- Integration with model based development especially with AUTOSAR.
- Analysis and improvements of test quality.

Motivation

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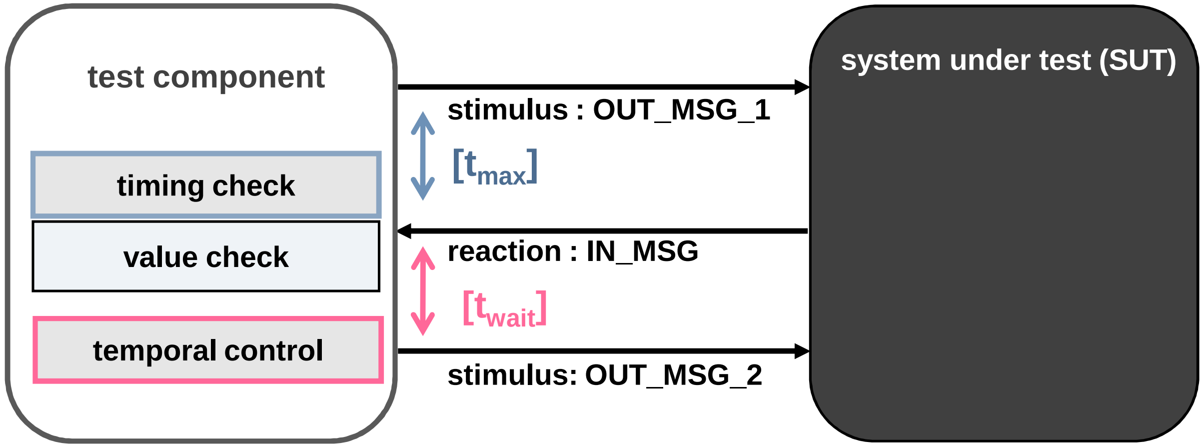
- Testing software based embedded systems steadily increase in complexity.
- In addition to that non-functional requirements, especially time related input-output behavior, have to be considered.
- Adequate and standardized test solutions are needed, which at least feature a minimum of flexibility, reusability and abstraction.

- ***GOAL: Provide a standardized testing solution for standardized development environments (e.g. AUTOSAR for Automotive Solutions).***
- ***GOAL: Tight Integration of real time testing concepts in an existing test specification environment (i.e. The Test and Testing Control Notation)***

TTCN-3 embedded Tasks

- ✓ TTCN-3 embedded for real time systems
- TTCN-3 embedded for continuous behavior
- TTCN-3 embedded hybrid behavior
- Graphical presentation format for TTCN-3 embedded
- Preparation for standardization

Real Time Test System Requirements



- Standard: assessment of functional behavior (e.g. message contents).
- ***Additional:*** exact measurement, comparison and assessment of message timing.
- ***Additional:*** temporal control of message dispatching.

Simple Real Time Scenario

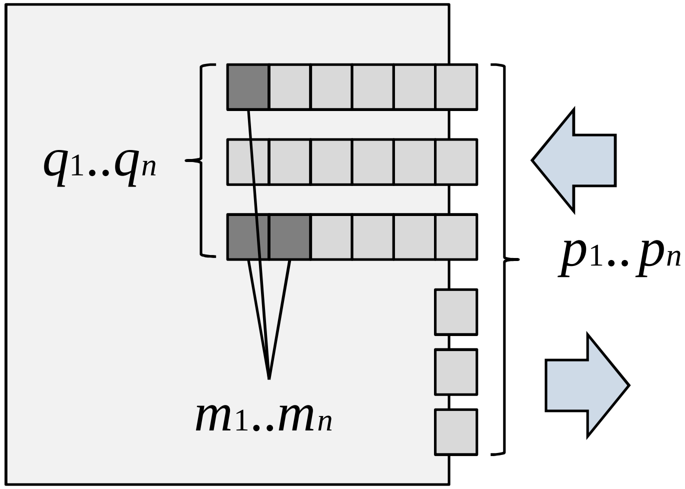

```
timer t1,t2;
p_out.send(OUT_MSG_1);
t1.start(t_max);
alt{
  []p_in.receive(IN_MSG_1){setverdict(pass)};
  []t1.timeout{setverdict(fail)}
}
t2.start(twait);
t2.timeout;
p_out.send(OUT_MSG_2);
p_in.receive(IN_MSG_2);
setverdict(pass);
```

```
var float r_time,s_time;
p_out.send(OUT_MSG_1);
s_time:=now;
p_in.receive(IN_MSG_1)-> timestamp r_time;
if(r_time>s_time+tmax) setverdict(fail);
wait(r_time+twait);
p_out.send(OUT_MSG_2);
p_in.receive(IN_MSG_2);
setverdict(pass);
```

Formalization of the Test System

$$TS = \{P, Q, C, M, TP, OP\}$$

- a set P of ports to communicate with the System Under Test (SUT),
- a set Q of input queues to organize the order of incoming messages,
- a set C of synchronized clocks to measure time and to simulate TTCN-3 timers,
- a set M of messages,
- a set $TP \subseteq TP_{data} \cup TP_{time}$ of predicates that are used to characterize the properties of incoming messages, and
- a set $OP = \{snap, check, enqueue, dequeue, first, encode, decode, match\}$ of time-consuming operations that are necessary to organize the handling of messages at ports.



$$snap : Q^{|Q|} \times C_0 \rightarrow S$$

$$decode : M \rightarrow M$$
$$match : M \times TP \rightarrow \mathbb{B}$$

$$check : Q \rightarrow \mathbb{B}$$
$$first : Q \rightarrow M$$
$$dequeue : Q \rightarrow M$$
$$enqueue : M \rightarrow Q$$

TTCN-3 Snapshot Semantics

```
alt{
  []p_in1.receive(IN_MSG_1){};
  []p_in2.receive(IN_MSG_2){};
  []t1.timeout{}
}
```

$s = \mathrm{snap}(q_{a1}, .., q_{an}, c_0)$

var (q^s, tpd) range over ALT^s

  if$(check(q^s))$ then

  $m = \mathrm{decode}(\mathrm{first}(q^s))$

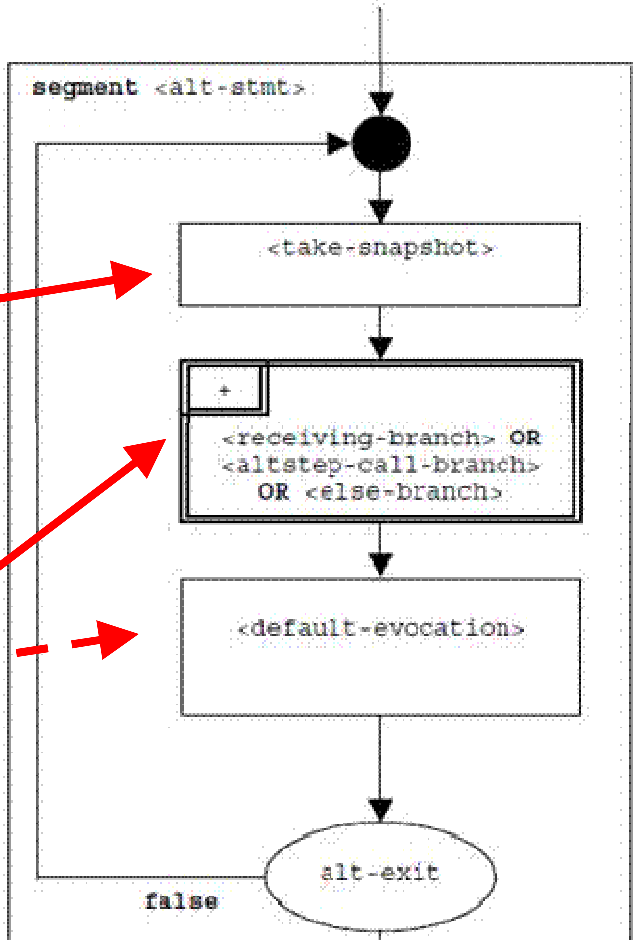
  if$(\mathrm{match}(m, tpd))$ then

    dequeue(q^s)

    alt-exit

  endif

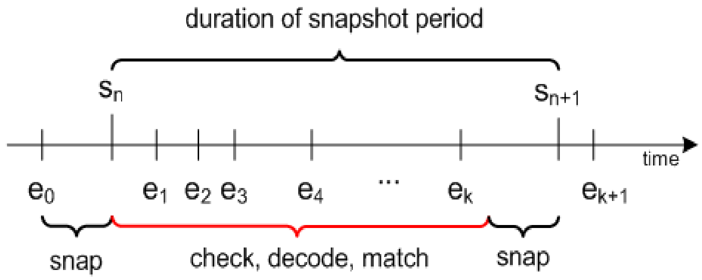
endif



Temporal estimations are only possible on basis of the assumption $t_{receive_{m_k}} \approx t(c^s)$, i.e. the time point of taking the snapshot approximates the reception time of messages.

Example: Comparison of Message Timing in Standard TTCN-3

- Arrival of messages $m_o,..,m_n$ and the timeout of timers $t_0,..,t_m$ are denoted by events $e_0,..,e_{k+1}$,
  - timing is measured by comparison of events, and
  - only events that occur in different snapshots are distinguishable.



$$t(e_0) \leq t(e_1) = t(e_2) = ... \leq t(e_{k+1})$$

- Duration between two consecutive snapshot denote the best accuracy of time measurement for standard TTCN-3. The duration depends on:
  - the ***number of messages*** that arrive and the ***number of ports*** (queues) to check,
  - the duration of check, decode, match for individual messages where the duration of decode and match is directly dependent on the ***content*** and ***structure*** of the ***message*** under observation.

Worst Case Influence of Time Consuming Operations

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- Problematic Situations: message burst over one or multiple ports.

- Each alternative is defined by: $a_k = (q_{a_k}, tpd_{a_k}) \in ALT \subseteq Q_{alt} \times TP_{alt}$
- *Simple assumption*: a new message has arrived at each port and none of the messages match.

$$worst(t(s_{n+1}) - t(s_n)) =$$
$$\sum_{x=1}^{l} (dur(check(q_{a_x}^{s_n})) + dur(decode(m^{q_{a_x}^{s_n}}))$$
$$+ dur(match(m^{q_{a_x}^{s_n}}), tp_{a_x})) + dur(snap)$$

Solution

- Seamless access to time
- Explicit measuring and access to the reception time of messages
- Utilities to handle comparison of time and temporal control of statement execution

Time: Concepts & Representation

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- Time model based on positive real numbers $t \in \mathbb{R}^+$
- Actual time $t = t(c_0)$ can be directly obtained by the user (**now** operator).
- TTCN-3 Language Level:
  - **now** operator returns time in seconds coded as a float value.
  - we allow arithmetic expressions on time values
  - precision of time measurement can be specified by means of the **precision** annotation

```
module{
  …
  var float myTimeVar;
  testcase myTc runs on myComp{
    …
    myTimeVar:=now+1.0;
    …
  }
} with{precision:=0.001}
```

Measurement of Time

- … to retrieve the enqueue time of a message,

```
p.receive(t)-> timestamp myTime;
// yields the reception time of a message
```

- and time measurement at any place in the test

```
var float myTime:= now;
// yields the actual time
```

Verification of Temporal Behaviour

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- Verification of enqueue time for incoming messages, procedure calls etc.

```
p.receive(t)-> timestamp timevar {
        if (timvar>max){setverdict(fail)}
        else {setverdict(pass)}
};
```

Temporal Control

- … at any place during test case execution,

```
wait(timepoint);
```

- and similar for message timing

```
wait(timepoint);
p.send(t);
```

Settable Error Verdict Necessary

- Double check the timing of test system behavior

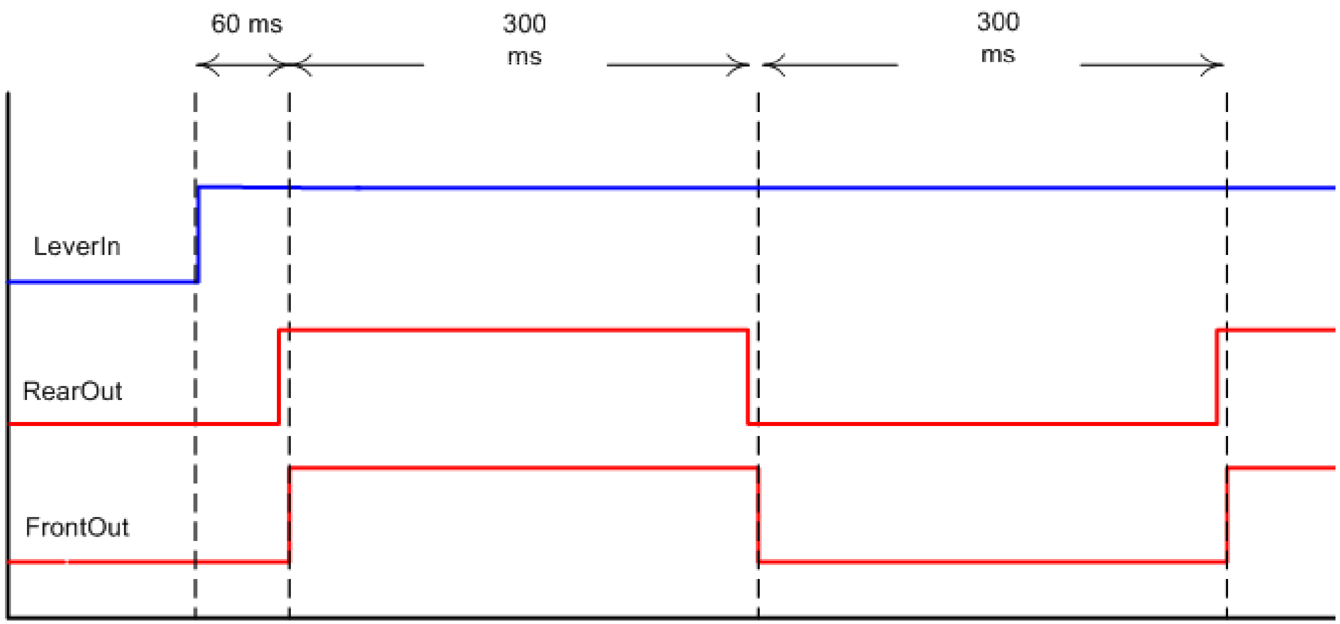
```
// test system to slow
wait(timepoint);
p.send(MSG_1);
if(now >= timepoint + tol) setverdict(error);

// SUT to slow
wait(timepoint);
p.send(MSG_1);
if(now >= timepoint + tol) setverdict(fail);

// SUT or test system to slow
wait(timepoint);
p.send(MSG_1);
if(now >= timepoint + tol) setverdict(inconclusive);
```

Testing Temporal Properties

- Maximum activation time 60 ms, phase length 600 ms
- Synchronization between signals: distance < 5 ms



Use Case: Test of an Indicator

Testing Activation of Indicator

```
testcase tc1( ) runs on IndicatorTestComponent{
  var float l_actv, r_actv, f_actv;
  const float TMAX = 0.06;
  activate(tc_timout);
  leverIn.send (LEFT);
  l_actv:= now;
  interleave{
    [ ] FrontOut.receive(ON) -> timestamp f_actv;
    [ ] RearOut.receive(ON) -> timestamp r_actv;
  }
  if ((f_actv-l_actv > TMAX)
       or (f_actv-r_actv > TMAX)){setverdict(fail)}
  setverdict(pass);
}
```

Use Case: Test of an Indicator

Testing Signal Synchronization

```
testcase tc2( ) runs on IndicatorTestComponent{
  var float r_actv, f_actv;
  const float TMAX = 0.005;
  activate(tc_timout);
  leverIn.send (LEFT);
  interleave{
    [ ] FrontOut.receive(ON) -> timestamp f_actv;
    [ ] RearOut.receive(ON) -> timestamp r_actv;
  }
  if (abs(r_actv-l_actv) > TMAX){setverdict(fail)}
  setverdict(pass);
}
```

Summary and Outlook

- RT concepts are tightly integrated with TTCN-3 and
  - provide means for an exact measurement, comparison and verification of the timing of incoming messages, and
  - enables the detection of timing problems during test execution and message dispatching

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- Implementation of Concepts
- Integration with high level modeling techniques (i.e. declarative approaches to specify timing constraints).
- Definition of coding and design guidelines to support the RT-capabilities of the newly introduced TTCN-3 concepts.

Contact and Info

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