UPPAAL tutorial

- What's inside UPPAAL
- The UPPAAL input languages
  (i.e. TA and TCTL in UPPAAL)

Timed Automata in UPPAAL

Clock Assignments

$x := n$

Variable Assignments

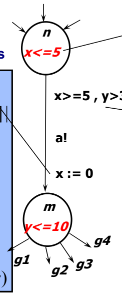
$i := Expr$

$Expr ::= i \mid i[Expr] \mid n \mid -Expr \mid Expr + Expr \mid Expr - Expr \mid Expr * Expr \mid Expr / Expr \mid (g_d \,?\, Expr : Expr)$

Location Invariants

$inv ::= x < n \mid x <= n \mid inv, inv$

clock natural number "and"



$g ::= g_c \mid g_d \mid g, g$ **Clock guards**

$g_c ::= x \otimes n \mid x \otimes y + n$

$g_d ::= Expr\ op\ Expr$ **Data guards**

$\otimes \in \{<, <=, ==, >=, >\}$

$op \in \{<, <=, ==, >=, >, !=\}$

Timed Automata in UPPAAL

Clock Assignments

$x := n$

Variable Assignments

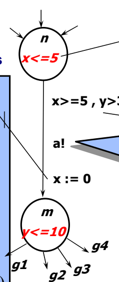
$i := Expr$

$Expr ::= i \mid i[Expr] \mid n \mid -Expr \mid Expr + Expr \mid Expr - Expr \mid Expr * Expr \mid Expr / Expr \mid (g_d \,?\, Expr : Expr)$

Location Invariants

$inv ::= x < n \mid x <= n \mid inv, inv$

clock natural number "and"

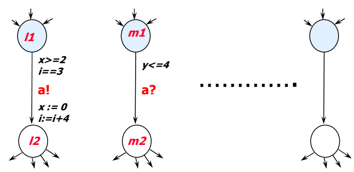


Actions:
- "a" name of action
- a! or a?
- one or zero per edge

guards

guards

Networks of Timed Automata



Two-way synchronization on **complementary** actions.

Closed Systems!

UPPAAL modeling language

- Networks of Timed Automata with Invariants
  - \+ urgent action channels,
  - \+ broadcast channels,
  - \+ urgent and committed locations,
  - \+ data-variables (with bounded domains),
  - \+ arrays of data-variables,
  - \+ constants,
  - \+ guards and assignments over data-variables and arrays…,
  - \+ templates with local clocks, data-variables, and constants
  - \+ C subset

Declarations in UPPAAL

- The syntax used for declarations in UPPAAL is similar to the syntax used in the C programming language.
- **Clocks**:
  - **Syntax:**

```
clock x1, …, xn ;
```

  - **Example:**
  - `clock x, y;` **Declares two clocks: x and y.**

Declarations in UPPAAL (cont.)

- **Data variables**
  - **Syntax:**

```
int n1, … ;
int[l,u] n1, … ;
int n1[m], … ;
```

Integer with "default" domain.
Integer with domain from "l" to "u".
Integer array w. elements n1[0] to n1[m-1].

- **Example;**
- `int a, b;`
- `int[0,1] a, b[5];`

Declarations in UPPAAL (cont.)

- Actions (or channels):
  - **Syntax:**

```
chan a, … ;
urgent chan b, … ;
```

Ordinary channels.
Urgent actions (described later)

- **Example:**
- `chan a, b[2];`
- `urgent chan c;`

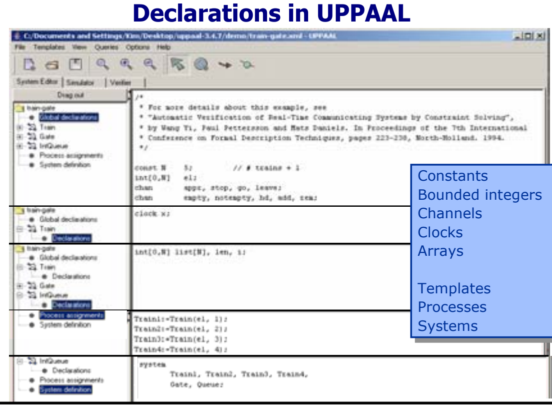
Declarations UPPAAL (const.)

- Constants
  - **Syntax:**

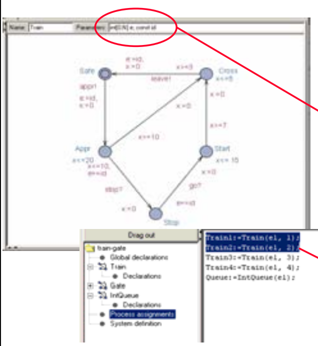
```
const int c1 = n1;
```

- **Example:**
- `const int[0,1] YES = 1;`
- `const bool NO = false;`

Declarations in UPPAAL



Templates in UPPAAL



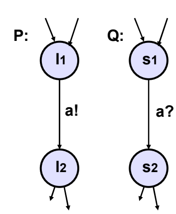
- Templates may be parameterised:

```
int v; const min; const max
int[0,N] e; const id
```

- Templates are instantiated to form processes:

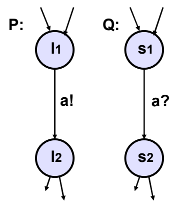
```
P:= A(i,1,5);
Q:= A(j,0,4);

Train1:=Train(el, 1);
Train2:=Train(el, 2);
```


Urgent Channels: Example 1



- Suppose the two edges in automata P and Q should be taken as soon as possible.
- I.e. as soon as both automata are ready (simultaneously in locations l_1 and s_1).
- How to model with invariants if either one may reach l_1 or s_1 first?

Urgent Channels: Example 1



- Suppose the two edges in automata P and Q should be taken as soon as possible
- I.e. as soon as both automata are ready (simultaneously in locations l_1 and s_1).
- How to model with invariants if either one may reach l_1 or s_1 first?
- **Solution**: declare action "a" as urgent.

Urgent Channels

```
urgent chan hurry;
```

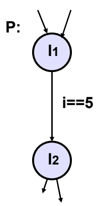
Informal Semantics:

- There will be <u>no delay</u> if transition with urgent action can be taken.

Restrictions:

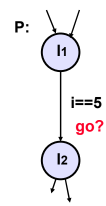
- <u>No clock guard</u> allowed on transitions with urgent actions.
- <u>Invariants</u> and <u>data-variable guards</u> are allowed.

Urgent Channel: Example 2

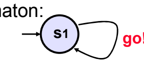


- Assume i is a data variable.
- We want P to take the transition from l1 to l2 as soon as i==5.

Urgent Channel: Example 2



- Assume i is a data variable.
- We want P to take the transition from l1 to l2 as soon as i==5.
- **Solution**: P can be forced to take transition if we add another automaton:



where "go" is an urgent channel, and we add "go?" to transition l1→l2 in automaton P.

Broadcast Synchronisation

```
broadcast chan a, b, c[2];
```

- If a is a broadcast channel:
  - `a!` = Emmision of broadcast
  - `a?` = Reception of broadcast
- A set of edges in different processes can synchronize if one is emitting and the others are receiving on the same b.c. channel.
- A process can always emit.
- Receivers *must* synchronize if they can.
- No blocking.

Urgent Location

Click "Urgent" in State Editor.

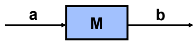
Informal Semantics:

- <u>No delay</u> in urgent location.

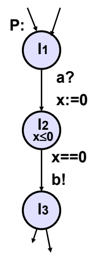
Note: the use of urgent locations **<u>reduces</u>** the number of clocks in a model, and thus the complexity of the analysis.

Urgent Location: Example

- Assume that we model a simple media M:



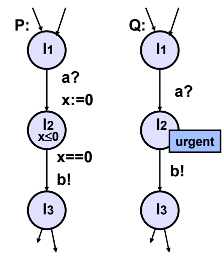
  that receives packages on channel a and immediately sends them on channel b.
- P models the media using clock x.



Urgent Location: Example

- Assume that we model a simple media M:

  that receives packages on channel a and immediately sends them on channel b.
- P models the media using clock x.
- Q models the media using **urgent location**.
- P and Q have the same behavior.



Committed Location

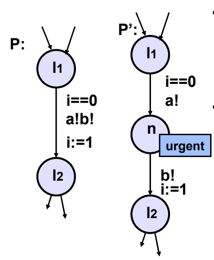
Click "Committed" i State Editor.

Informal Semantics:

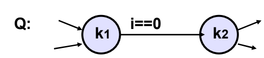
- No delay in committed location.
- Next transition must involve automata in committed location.

Note: the use of committed locations **reduces** the number of interleaving in state space exploration (and also the number of clocks in a model), and thus allows for more space and time efficient analysis.

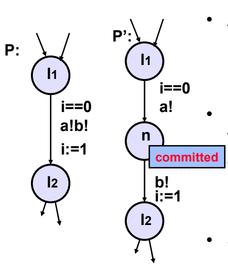
Committed Location: Example 1



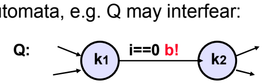
- **Assume:** we want to model a process (P) simultaneously sending message a and b to two receiving processes (when i==0).
- P' sends "a" two times at the same time instant, but in location "n" other automata, e.g. Q may interfear



Committed Location: Example 1

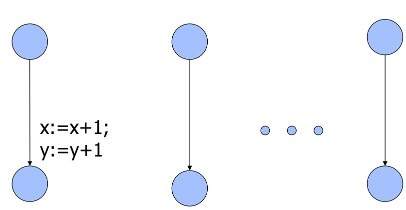


- **Assume:** we want to model a process (P) simultaneously sending message (a) to two receiving processes (when i==0).
- P' sends "a" two times at the same time instant, but in location "n" other automata, e.g. Q may interfear:



- **Solution:** mark location n "committed" in automata P' (instead of "urgent").

Committed Locations
(example: atomic sequence in a network)

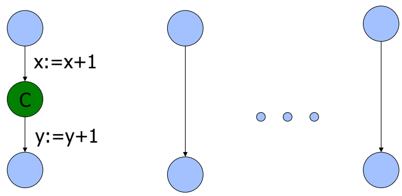


If the sequence becomes too long, you can split it ...

Committed Locations

(example: atomic sequence in a network)

Semantics: the time spent on C-location should be zero !

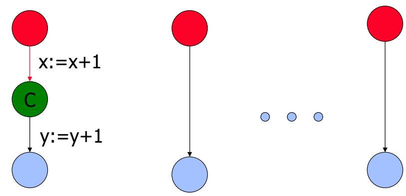


25

Committed Locations

(example: atomic sequence in a network)

Semantics: the time spent on C-location should be zero !

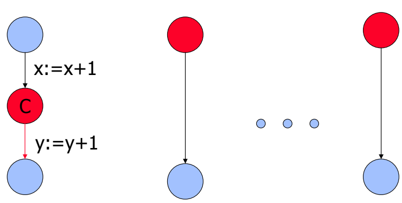


26

Committed Locations

(example: atomic sequence in a network)

Semantics: the time spent on C-location should be zero !

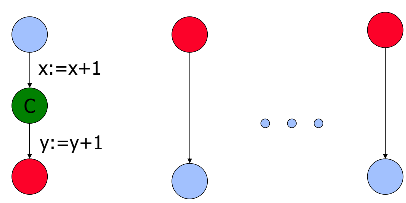


Now, only the committed (red) transition can be taken!

27

Committed Locations

(example: atomic sequence in a network)



28

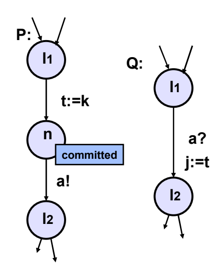
Committed Locations

- A trick of modeling (e.g. to model multi-way synchronization using handshaking)
- More importantly, it is a simple and efficient mechanism for state-space reduction!
  In fact, it is a simple form of 'partial order reduction'
- It is used to avoid intermediate states, interleavings:
  Committed states are not stored in the passed list
  Interleavings of any state with a committed location will not be explored

29

Committed Location: Example 2

- **Assume:** we want to pass the value of integer "k" from automaton P to variable "j" in Q.
- The value of k can is passed using a global integer variable "t".
- Location "n" is committed to ensure that no other automat can assign "t" before the assignment "j:=t".



30

More Expressions

- New operators (not clocks):
  - Logical:
    - && (logical and), || (logical or), ! (logical negation),
  - Bitwise:
    - ^ (xor), & (bitwise and), | (bitwise or),
  - Bit shift:
    - << (left), >> (right)
  - Numerical:
    - % (modulo), <? (min), >? (max)
  - Compound Assignments:
    - +=, -=, *=, /=, ^=, <<=, >>=
  - Prefix or Postfix:
    - ++ (increment), -- (decrement)

More on Types

- Multi dimensional arrays
  e.g. int b[2][3];
- Array initialiser:
  e.g. int b[2][3] := { {1,2,3}, {4,5,6} };
- Arrays of channels, clocks, constants.
  e.g.
  - chan a[3];
  - clock c[3];
  - const k[3] { 1, 2, 3 };
- Broadcast channels.
  e.g. broadcast chan a;

Extensions

Select statement

- Models non-deterministic choise
- `x : int[0,42]`

Types

- Record types
- Type declarations
- Meta variables:
  not stored with state
  `meta int x;`

Forall / Exists Expressions

- `forall (x:int[0,42]) expr`
  true if expr is true for *all* values in [0,42] of x
- `exists (x:int[0,4]) expr`
  true if expr is true for *some* values in [0,42] of x

Example:

```
forall
(x:int[0,4])array[x];
```


Advanced Features

- Priorities on channels
  ```
  chan a,b,c,d[2],e[2];
  chan priority a,d[0] < default < b,e
  ```
- Priorities on processes
  ```
  system A < B,C < D;
  ```
- Functions
  C-like functions with return values

UPPAAL specification language

TCTL Quantifiers in UPPAAL

- E - exists a path ("**E**" in UPPAAL).
- A - for all paths ("**A**" in UPPAAL).
- G - all states in a path ("**[]**" in UPPAAL).
- F - some state in a path ("**<>**" in UPPAAL).

You may write the following queries in UPPAAL:

- **A[]p, A<>p, E<>p, E[]p and p --> q**

AG p (A[]p), **AF p** (A<>p), **EF p** (E<>p), **EG p** (E[]p)

p and q are "local properties"

"Local Properties"

`A[]p, A<>p, E<>p, E[]p, p-->p`
where `p` is a local property

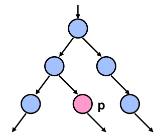
automaton location — data guard — clock guard

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

process/ name

E<>p – "p Reachable"

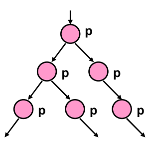
- **`E<> p`** – it is possible to reach a state in which p is satisfied.



- p is true in (at least) one reachable state.

A[]p – "Invariantly p"

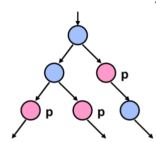
- **`A[] p`** – p holds invariantly.



- p is true in all reachable states.

A<>p – "Inevitable p"

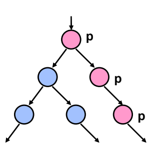
- **`A<> p`** – p will inevitable become true, the automaton is guaranteed to eventually reach a state in which p is true.



- p is true in some state of all paths.

E[ ] p – "Potentially Always p"

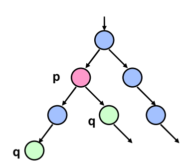
- **`E[] p`** – p is potentially always true.



- There exists a path in which p is true in all states.

p --> q– "p lead to q"

- **p** --> **q** – if p becomes true, q will inevitably become true. same as A[](**p** imply A<> **q**)



- In all paths, if p becomes true, q will inevitably become true.