Concurrent Processes

SE 3BB4

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Concurrent Processes

- Concurrent process is a **composition** of sequential processes.
- *Hidden assumption*: Concurrent systems can be decomposed into sequential systems.

1. Process (sequential): A sequence of action

$$\downarrow$$

2. Model of a process: Finite state machine

$$\downarrow$$

3. A possible implementation of processes: Threads in Java.

The approach 1,2,3 is not the only one, but we will concentrate on it in this course.

Concepts: Processes - units of sequential execution

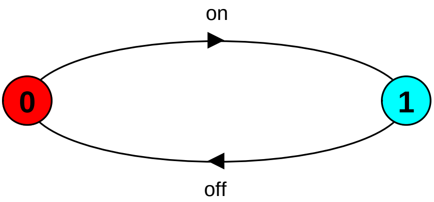
Models: Finite State Processes (FSP)
To model processes as sequences of actions
Labelled Transition Systems (LTS)
To analyze,display and animate behaviour

Practice: Java threads

- LTS - graphical form
- FSP - algebraic form

- Tool LTSA takes FSP and analyses them.
- Different names for the same concepts:
  LTS - automata, state machines
  FSP - CSP (Communicating Sequential Processes), Processes in Process Algebras

- A process is the execution of a sequential program. It is modeled as a finite state machine which transits from state to state by executing a sequence of atomic actions.



a light switch
LTS

on→off→on→off→on→off→ ....

a sequence of actions or *trace*

- How can it be modelled by an algebraic expression?

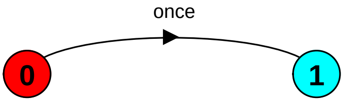
FSP - action prefix

- If x is an action and P is a process then

$$(x \rightarrow P)$$

describes a process that initially engages in the action x and then behaves exactly as described by P.

```
ONESHOT = (once -> STOP).
```



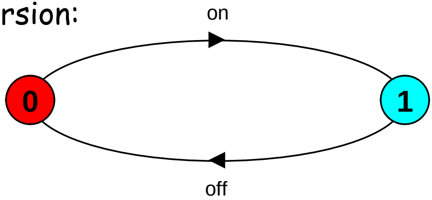
ONESHOT state machine

(terminating process)

- Convention: actions begin with lowercase letters while PROCESSES begin with uppercase letters

Repetitive behaviour uses recursion:

```
SWITCH = OFF,
OFF    = (on -> ON),
ON     = (off-> OFF).
```



Substituting to get a more succinct definition:

```
SWITCH = OFF,
OFF    = (on ->(off->OFF)).
```

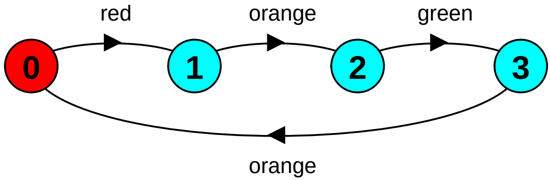
And again:

```
SWITCH = (on->off->SWITCH).
```

FSP model of a traffic light :

```
TRAFFICLIGHT = (red->orange->green->orange
                 -> TRAFFICLIGHT).
```

LTS generated using *LTSA*:



Trace:

red→orange→green→orange→red→orange→green …

- If x and y are actions then

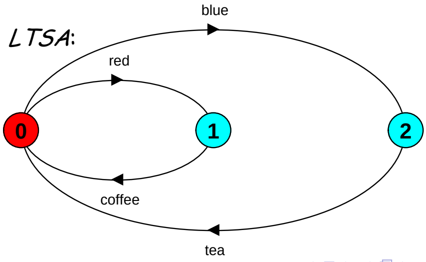
$$(x \to P \mid y \to Q)$$

describes a process which initially engages in either of the actions x or y. After the first action has occurred, the subsequent behavior is described by P if the first action was x and Q if the first action was y.

FSP model of a drinks machine :

```
DRINKS = (red->coffee->DRINKS
         |blue->tea->DRINKS
         ).
```

LTS generated using *LTSA*:

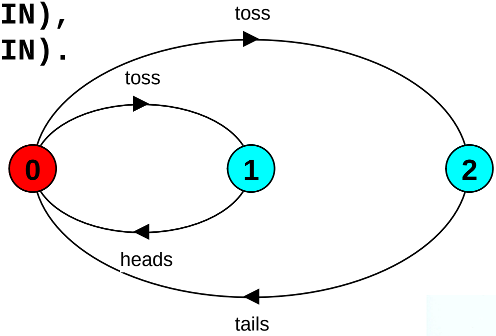


Possible traces?

Non-deterministic choice

- Process $(x \rightarrow P \mid x \rightarrow Q)$ describes a process which engages in x and then behaves as either P or Q.

```
COIN = (toss->HEADS|toss->TAILS),
HEADS= (heads->COIN),
TAILS= (tails->COIN).
```

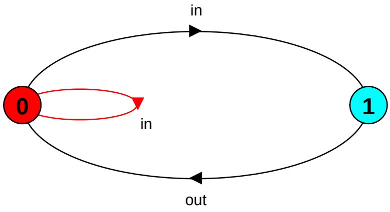


Tossing a coin.

Possible traces?

- How do we model an unreliable communication channel which accepts **in** actions and if a failure occurs produces no output, otherwise performs an **out** action?

Use non-determinism...




```
CHAN = (in->CHAN
       |in->out->CHAN
       ).
```

FSP -indexed processes and actions

- Single slot buffer that inputs a value in the range 0 to 3 and then outputs that value.

```
BUFF = (in[i:0..3]->out[i]-> BUFF).
```

equivalent to

```
BUFF = (in[0]->out[0]->BUFF
       |in[1]->out[1]->BUFF
       |in[2]->out[2]->BUFF
       |in[3]->out[3]->BUFF
       ).
```

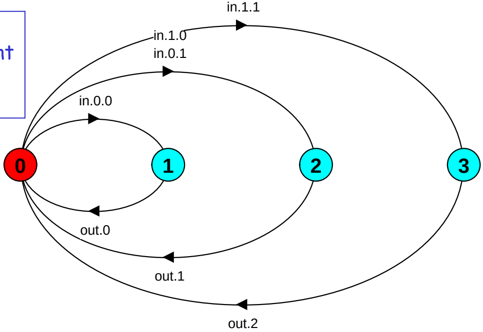
indexed actions generate labels of the form *action.index*

or using a process parameter with default value:

```
BUFF(N=3) = (in[i:0..N]->out[i]-> BUFF).
```

More helpful syntax

Local indexed process definitions are equivalent to process definitions for each index value



index expressions to model calculation:

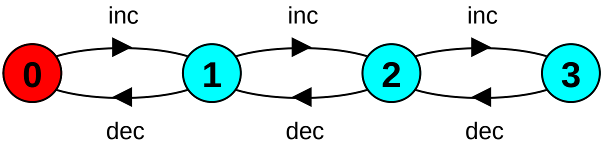
```
const N = 1
range T = 0..N
range R = 0..2*N

SUM         = (in[a:T][b:T]->TOTAL[a+b]),
TOTAL[s:R] = (out[s]->SUM).
```

- Notation: $in[0][1] = in.0.1$, $out[2] = out.2$, etc.

FSP - guarded actions

- The choice (*when* $B\ x \to P \mid y \to Q$) means that when the guard B is true then the actions x and y are both eligible to be chosen, otherwise if B is false then the action x cannot be chosen.

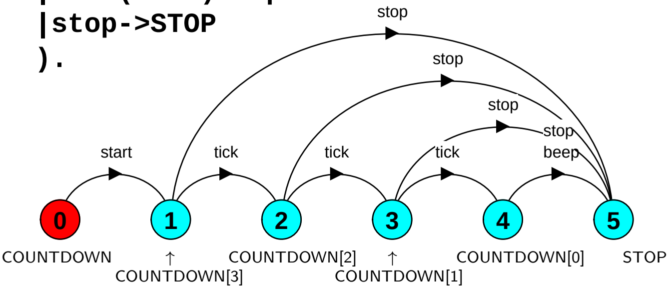
```
COUNT (N=3)   = COUNT[0],
COUNT[i:0..N] = (when(i<N) inc->COUNT[i+1]
                |when(i>0) dec->COUNT[i-1]
                ).
```



- It usually occurs in the form (*when* $B\ x \to P \mid$ *when* $\neg B\ y \to Q$), so the choice between $x \to P$ and $y \to Q$ is exclusive.

- A countdown timer which beeps after N ticks, or can be stopped.

```
COUNTDOWN (N=3)   = (start->COUNTDOWN[N]),
COUNTDOWN[i:0..N] =
        (when(i>0) tick->COUNTDOWN[i-1]
        |when(i==0)beep->STOP
        |stop->STOP
        ).
```



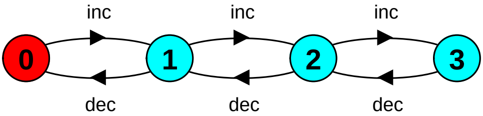
- The domain of B must be **finite**. Otherwise we cannot create any LTS.

```
COUNT (N=3)    = COUNT[0],
COUNT[i:0..N] = (when(i<N) inc->COUNT[i+1]
                |when(i>0) dec->COUNT[i-1]
                ).
```

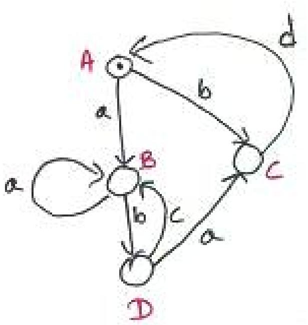
- In this case the domains of $(i < N)$ and $(i > 0)$ consist of four elements $i = 0, 1, 2, 3$, so COUNT expands to:

COUNT $=$ COUNT0
COUNT0 $=$ (inc $- >$ COUNT1)
COUNT1 $=$ (inc $- >$ COUNT2 $\mid$ dec $- >$ COUNT0)
COUNT2 $=$ (inc $- >$ COUNT3 $\mid$ dec $- >$ COUNT1)
COUNT3 $=$ (dec $- >$ COUNT2)

- so, the states correspond to the values $0, 1, 2, 3$, and LTS is:



LTS → FSP



$\Longrightarrow$

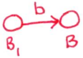
$$A = (a \rightarrow B \mid b \rightarrow C)$$
$$B = (a \rightarrow B \mid b \rightarrow D)$$
$$C = (d \rightarrow A)$$
$$D = (a \rightarrow C \mid c \rightarrow B)$$

$$A = (a \rightarrow b \rightarrow B \mid b \rightarrow (a \rightarrow c \rightarrow A \mid b \rightarrow B))$$
$$B = (a \rightarrow c \rightarrow (a \rightarrow A \mid b \rightarrow b))$$

often some parentheses can be omitted for readability, i.e., we may write:

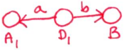
$$A = a \rightarrow b \rightarrow B \mid b \rightarrow (a \rightarrow c \rightarrow A \mid b \rightarrow B)$$
$$B = a \rightarrow c \rightarrow (a \rightarrow A \mid b \rightarrow B)$$

$B_1 = b \rightarrow B$ $\Longrightarrow$



$A_1 = c \rightarrow A$

$D_1 = a \rightarrow A_1 \mid b \rightarrow B$ $\Longrightarrow$

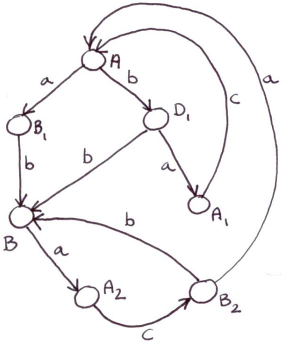


$A = a \rightarrow B_1 \mid b \rightarrow D_1$

$B_2 = a \rightarrow A \mid b \rightarrow B$

$A_2 = c \rightarrow B_2$

$B = a \rightarrow A_2$



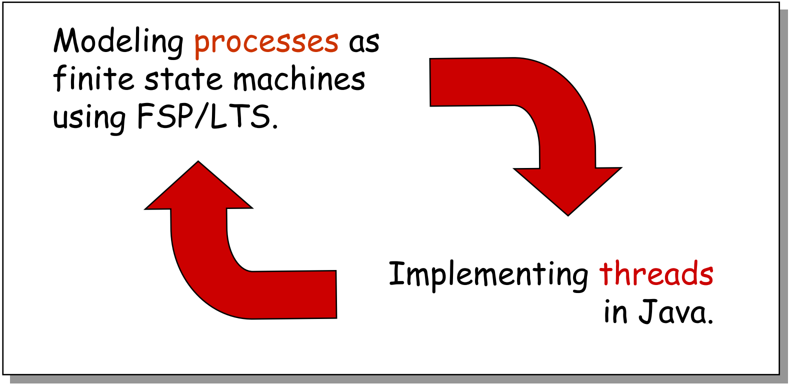
Process alphabets

- The alphabet of a process is the set of actions in which it can engage.
- Process alphabets are implicitly defined by the actions in the process definition.
- Alphabet extension can be used to extend the implicit alphabet of a process:

  $$WRITER = (write[1] \rightarrow write[3] \rightarrow WRITER) + \{write[0..3]\}$$

  Alphabet of *WRITER* is the set $\{write[0..3]\} = \{write[0], write[1], write[2], write[3]\}$.

Implementing processes



- Process $\Longrightarrow$ models as FSP or LTS
- Thread $\Longrightarrow$ implementation in Java

Concurrency, Parallelism: definitions

- Concurrency: Logically simultaneous processing.Does not imply multiple processing elements (PEs). Requires interleaved execution on a single PE.
- Parallelism: Physically simultaneous processing.Involves multiple PEs and/or independent device operations.

The textbook uses the terms parallel and concurrent interchangeably and generally do not distinguish between real and pseudo-concurrent execution.

- **These are the authors definitions!**
- **They are NOT universally accepted!**
- **WHAT ABOUT SIMULTANEITY AND SIMULTANEOUS EXECUTIONS?! They may make a substantial difference!**

Modeling Concurrency

- How should we model process execution speed?
  Arbitrary speed (we abstract away time)
- How do we model concurrency?
  Arbitrary relative order of actions from different processes (**interleaving** but preservation of each process order)

!!? MANY CONSIDER THIS APPROACH AS AN **OVERSIMPLIFICATION**!

- What is the result?
  It provides a general model independent of scheduling (**asynchronous** model of execution)

!!? MANY CONSIDER THE LAST STATEMENT AS AN UNJUSTIFIED OVERSTATEMENT!

- If P and Q are processes then $(P||Q)$ represents the concurrent execution of P and Q. The operator $||$ is the parallel composition operator.

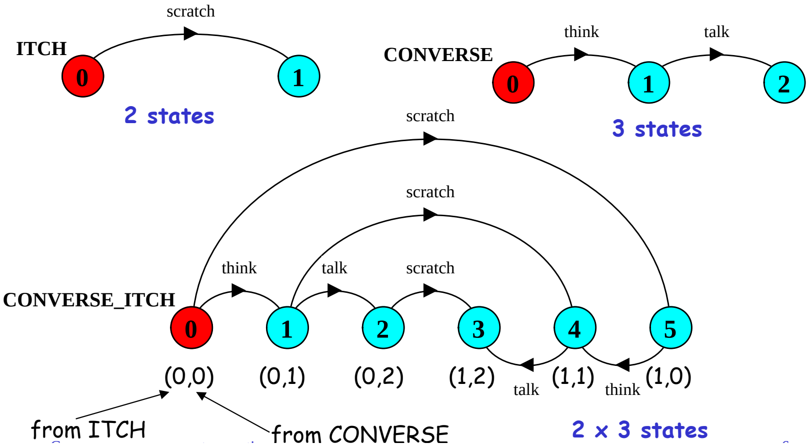
```
ITCH   = (scratch->STOP).
CONVERSE = (think->talk->STOP).

||CONVERSE_ITCH = (ITCH || CONVERSE).
```

Disjoint alphabets

```
think→talk→scratch
think→scratch→talk
scratch→think→talk
```

Possible traces as a result of action interleaving.

Parallel composition - action interleaving



- Transformation into LTS is NOT the best solution, transformation into *Petri nets* is better!

Parallel composition: Algebraic Laws

- Commutativity: $P \parallel Q = Q \parallel P$
- Associativity: $P \parallel (Q \parallel R) = (P \parallel Q) \parallel R = P \parallel Q \parallel R$

Problem: *What these equalities mean?*

- The set if traces that is generated is the same for the left and the right side, but is this sufficient?
- Semantics is not defined! In a decent scientific paper such "laws" would not survive!
- *Semantics should be defined before!*
- LTS are also the same for the left and right side of equations? Do they define semantics?

Example (Clock Radio)

$$CLOCK = tick \rightarrow CLOCK$$

$$RADIO = on \rightarrow off \rightarrow RADIO$$

$$\parallel CLOCK\_RADIO = CLOCK \parallel RADIO$$

Modelling interaction - shared actions

- If processes in a composition have actions in common, these actions are said to be *shared*. Shared actions are the way that process interaction is modeled. While unshared actions may be arbitrarily interleaved, a shared action must be executed at the same time by all processes that participate in the shared action.

Example (Maker-user)

$$MAKER = make \rightarrow ready \rightarrow MAKER$$

$$USER = ready \rightarrow use \rightarrow USER$$

$$\| \; MAKER\_USER = Maker \parallel USER$$

Traces:

$make \rightarrow ready \rightarrow use \rightarrow make \rightarrow ready \rightarrow make \rightarrow use \rightarrow \ldots$

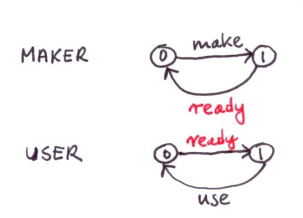
Example (Maker-user)

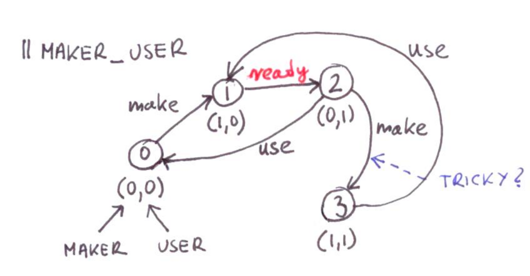
$$MAKER = make \rightarrow ready \rightarrow MAKER$$

$$USER = ready \rightarrow use \rightarrow USER$$

$$\| \; MAKER\_USER = Maker \; \| \; USER$$

LTS:





- IT IS MUCH EASIER AND MORE INTUITIVE TO REPRESENT SYSTEMS LIKE MAKER-USER WITH *PETRI NETS*!