Lecture 1: Introduction, Processes & Threads

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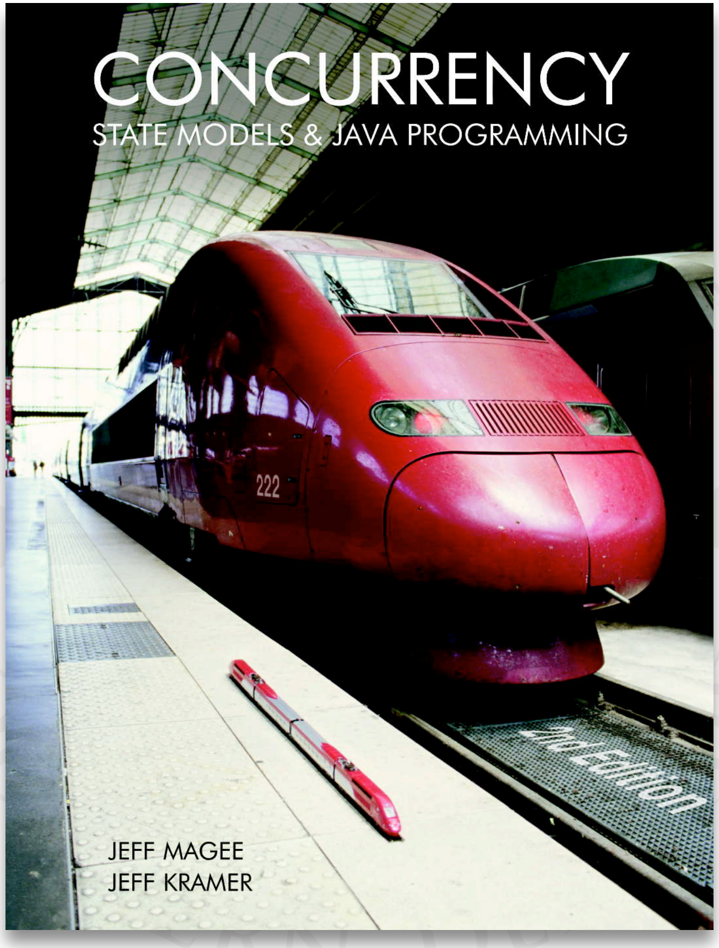
Textbook

[M&K] Concurrency: State Models & Java Programs (2nd edition). Jeff Magee & Jeff Kramer. Wiley. 2006, ISBN: 0-470-09355-2



Course Home Page

http://imada.sdu.dk/~petersk/DM519/

What is a Concurrent Program?

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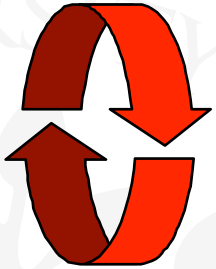

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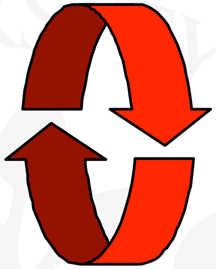
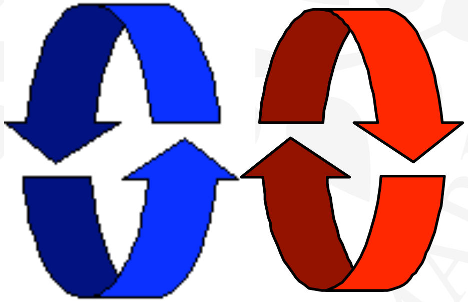


A ***concurrent*** **program has multiple threads of control:**

- perform multiple computations in parallel
- control multiple external activities occurring simultaneously.



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Increased application responsiveness

– High-priority thread for user requests

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- New kinds of errors possible(!):
  - Deadlock, starvation, priority inversion, interference, …

Solution: Model-based Design

REAL PROBLEM

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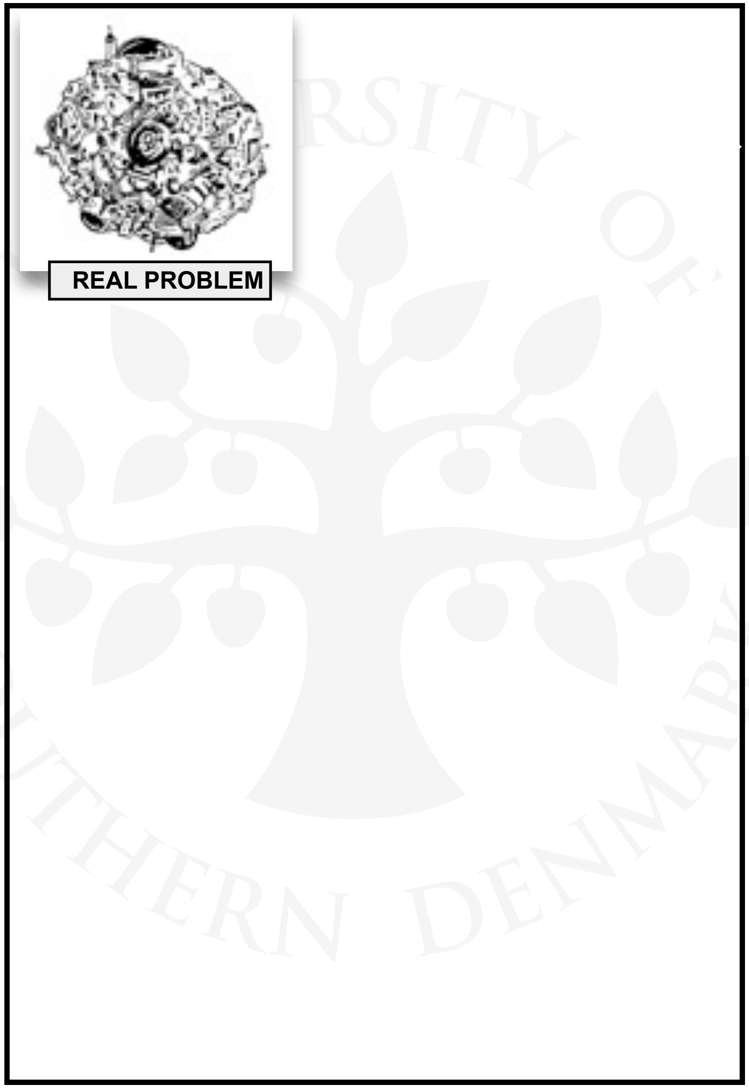
Model: a simplified representation of the real world.

- focus on *concurrency aspects*



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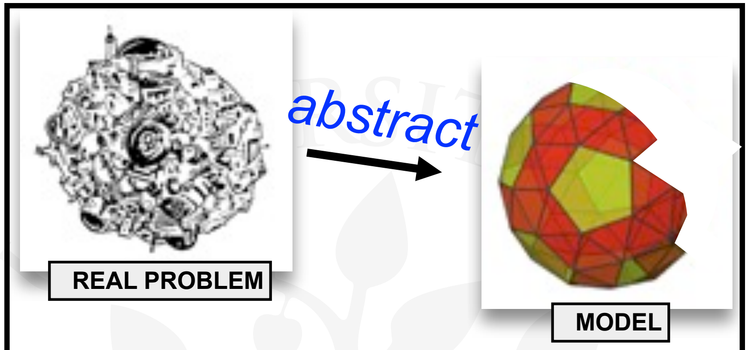

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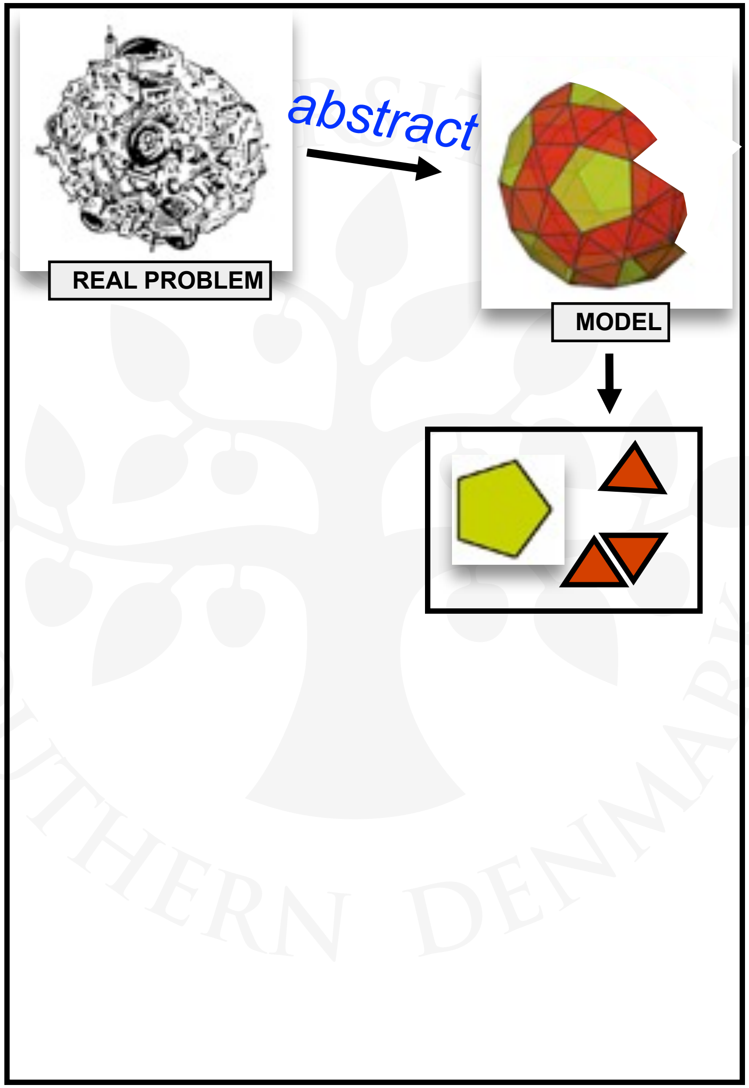

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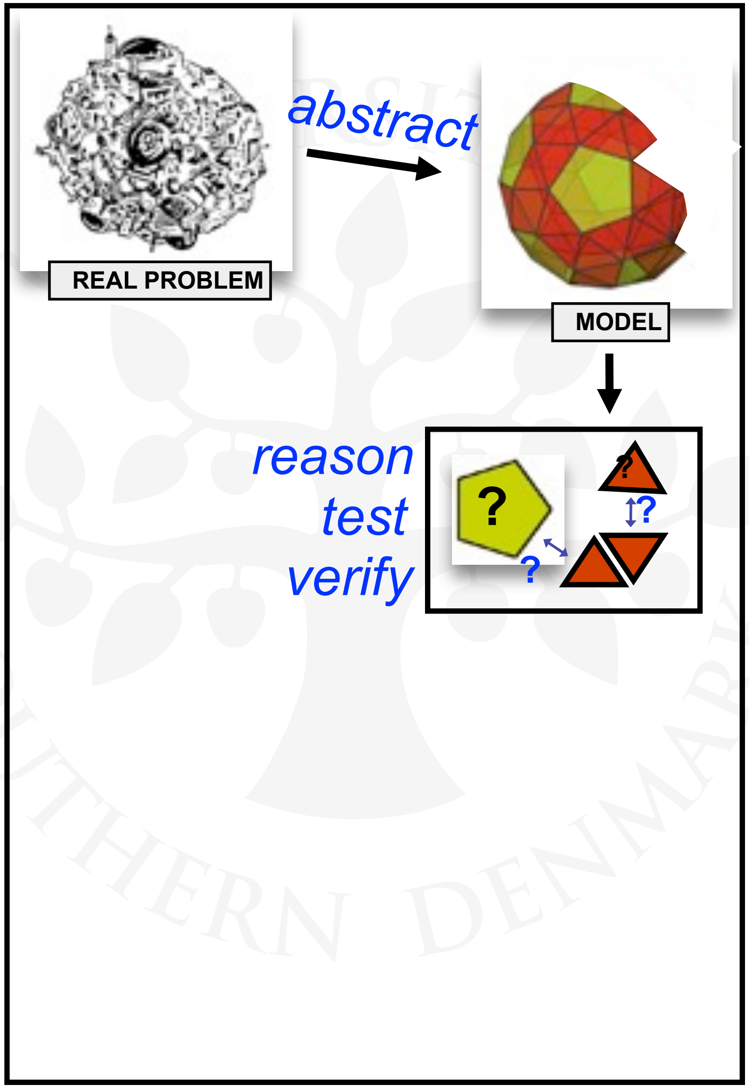

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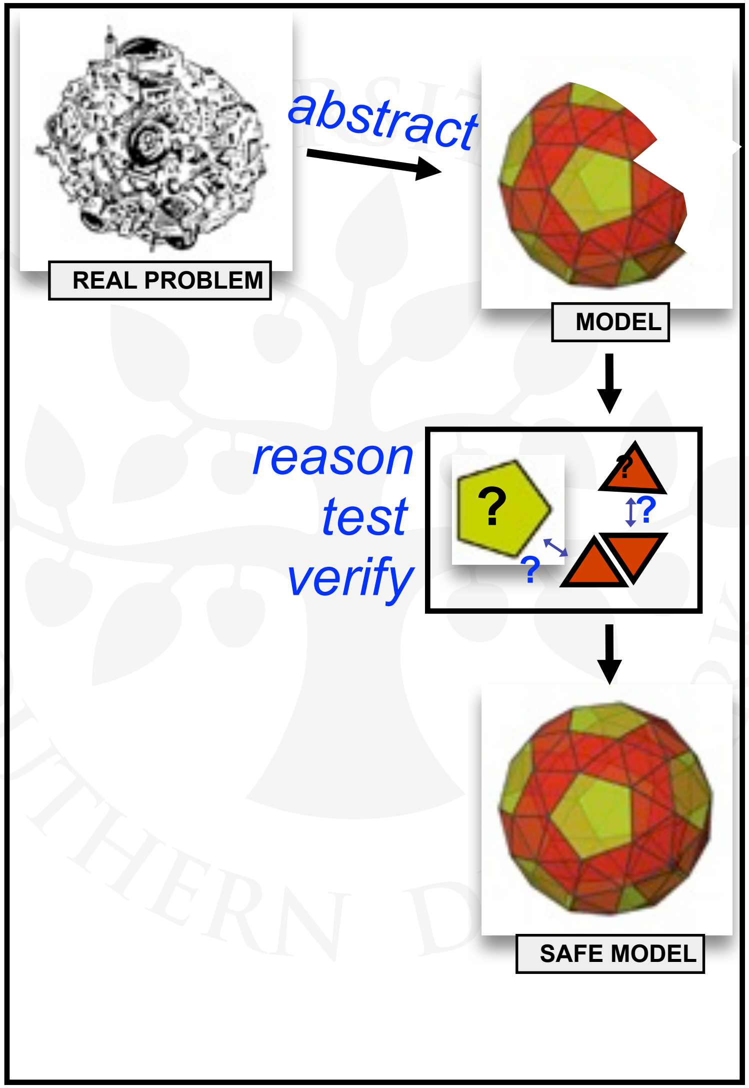

REAL PROBLEM

abstract

MODEL

reason
test
verify

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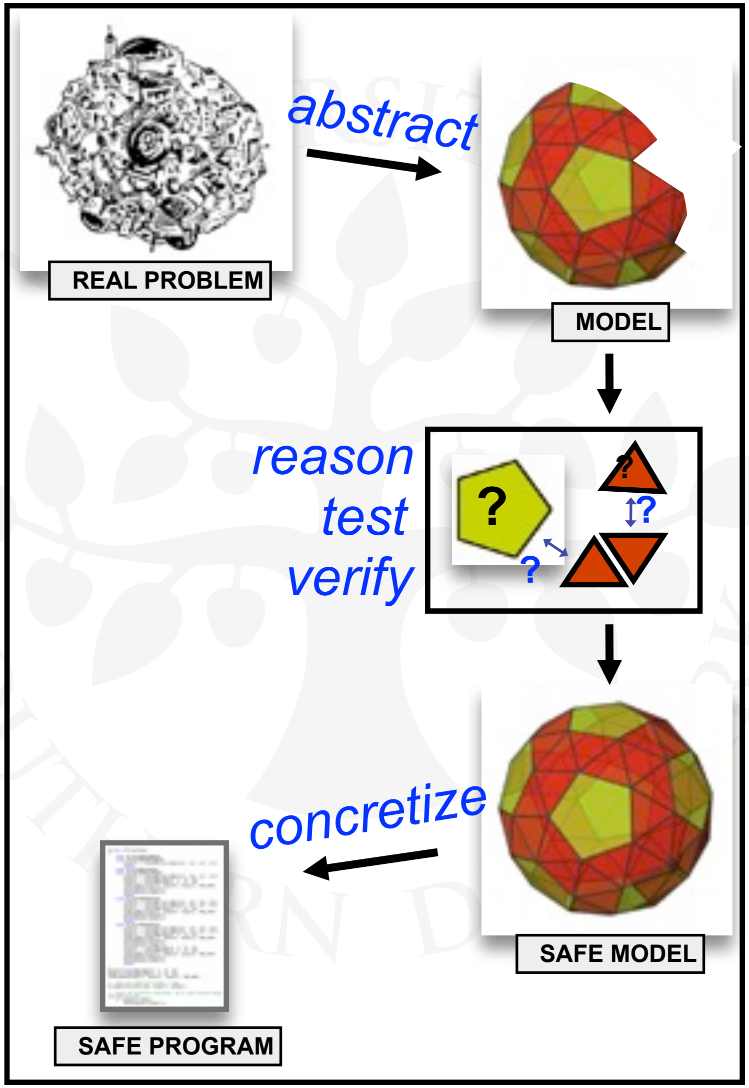
Implement *concrete program*



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Implement models in Java

Relate models and implementations

How to achieve them?

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Lectures

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Theoretical exercises during the discussion sections

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Practical exercises in your study groups

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- mid-quarter deadline for model
- end-quarter deadline for implementation & report

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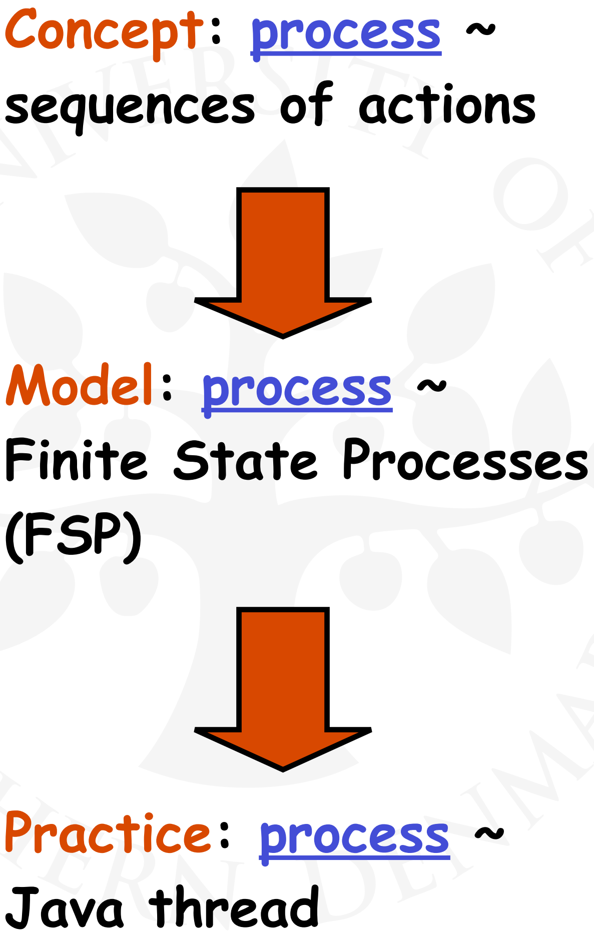

Concept: process ~ sequences of actions

Model: process ~ Finite State Processes (FSP)

Practice: process ~ Java thread

Modelling Processes

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- FSP - algebraic form

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- FSP - algebraic form
- LTS - graphical form

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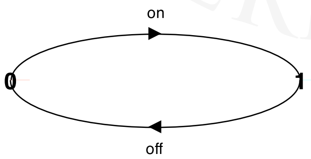
```



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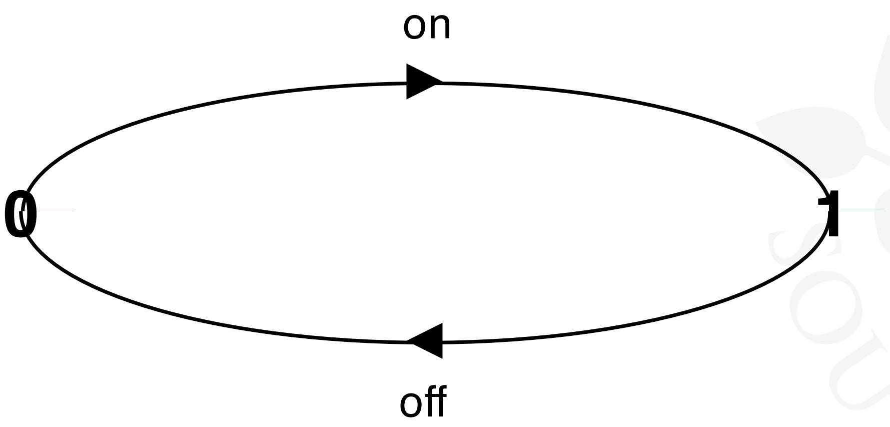

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LTS

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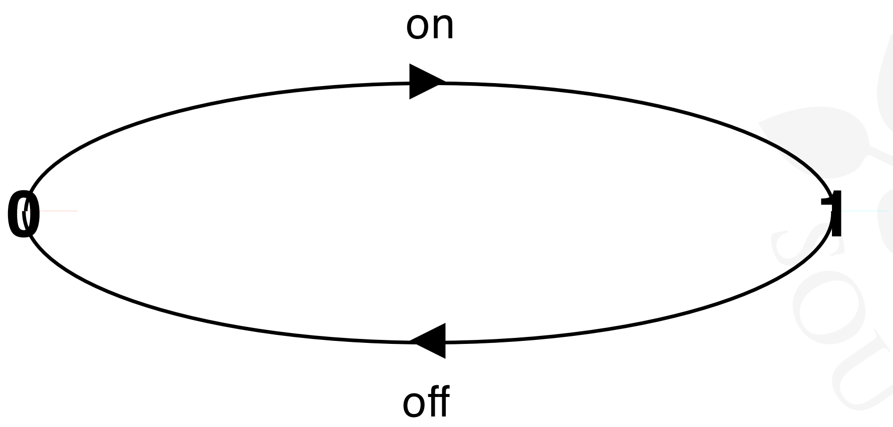

a light switch **LTS**

`on→off→on→off→on→off→ ……….`

a sequence of actions or **trace**

FSP - action prefix & recursion

Repetitive behaviour uses recursion:

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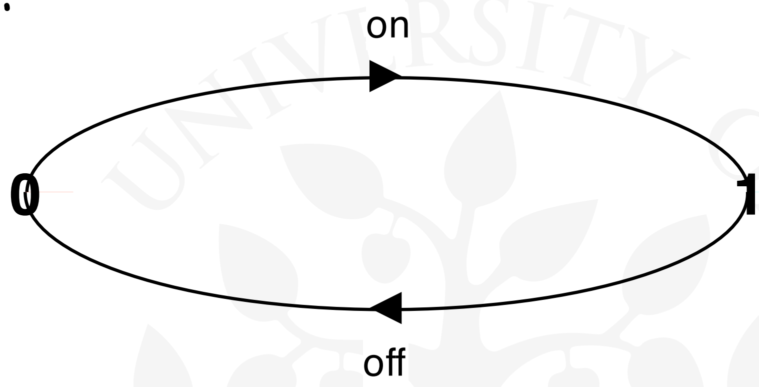

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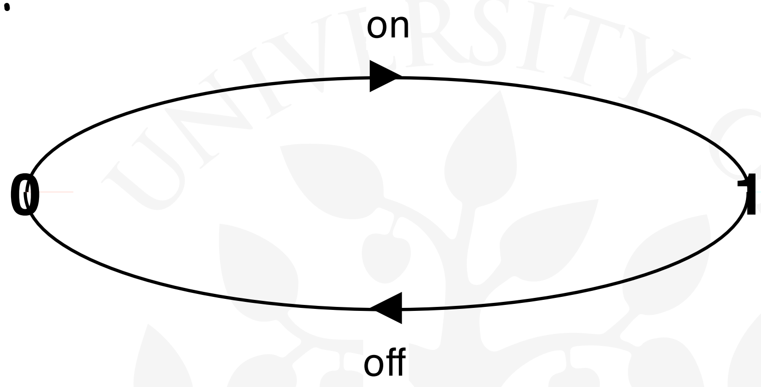

Substituting to get a more succinct definition:

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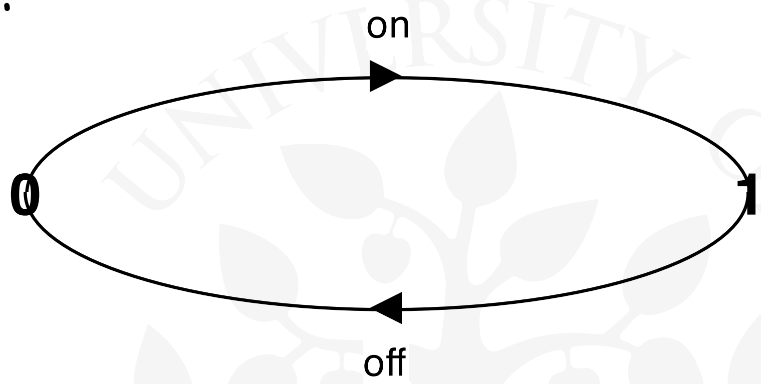

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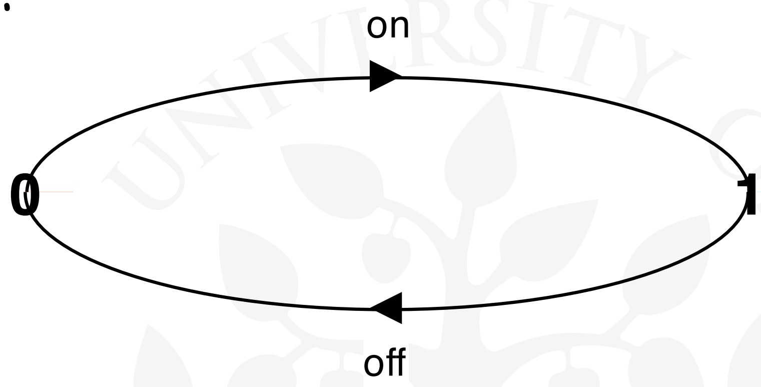

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SWITCH = (on->off->SWITCH).
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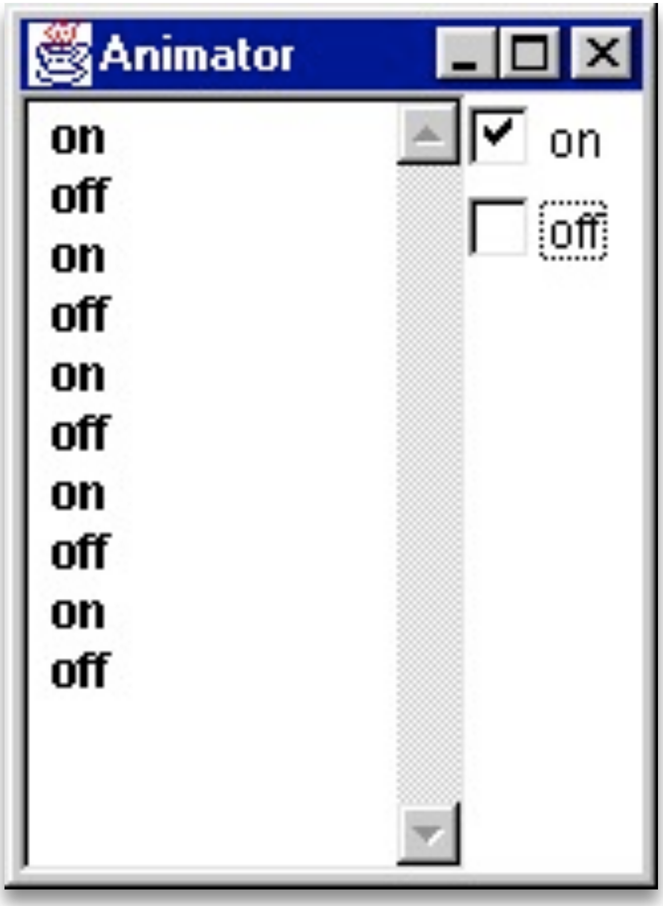
Animation using LTSA



```
on
off
on
off
on
off
on
off
on
off
```

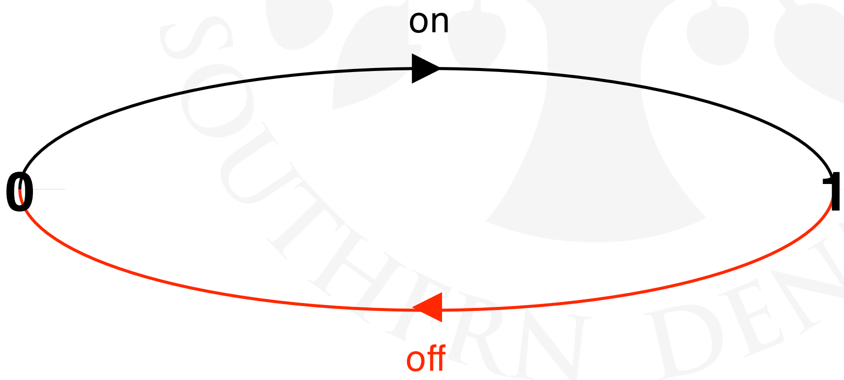
☑ on

□ off

The LTSA animator can be used to produce a **trace**.

Ticked actions are eligible for selection.

In the LTS, the last action is highlighted in red.



FSP - action prefix

FSP model of a traffic light:

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TRAFFICLIGHT = (red->orange->green->orange
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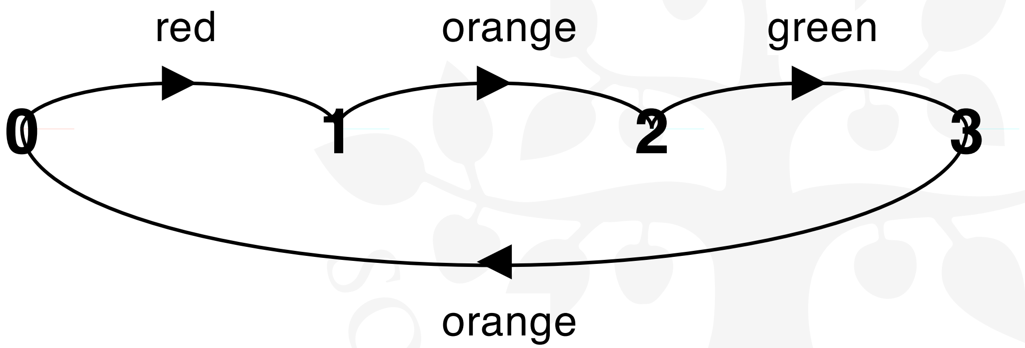

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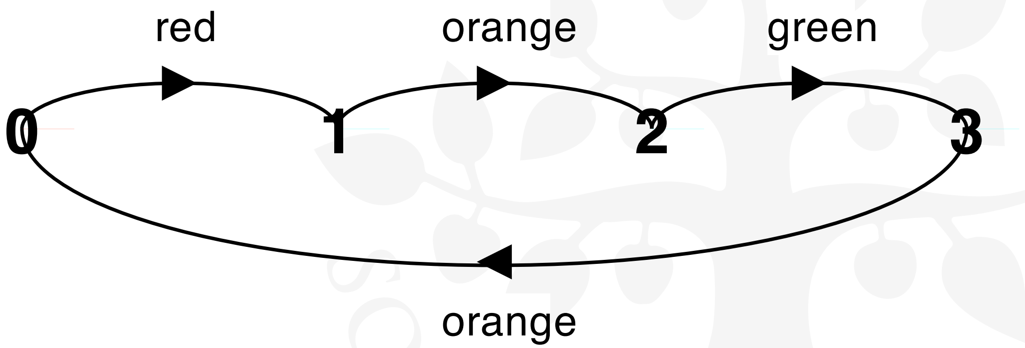

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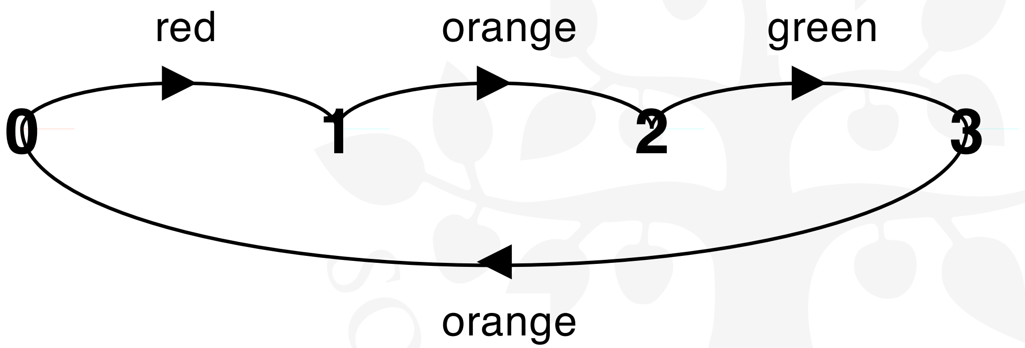

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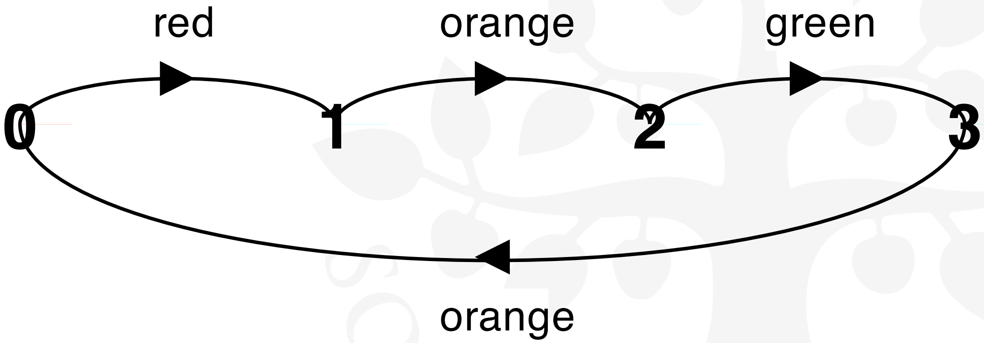

Trace(s)?

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

What would the LTS look like for?:

```
T = (red->orange->green->orange->STOP).
```

FSP - choice

If **x** and **y** are actions then **(x-> P | y-> 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**.

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Who or what makes the choice?

Is there a difference between input and output actions?

FSP - choice

FSP model of a drinks machine :

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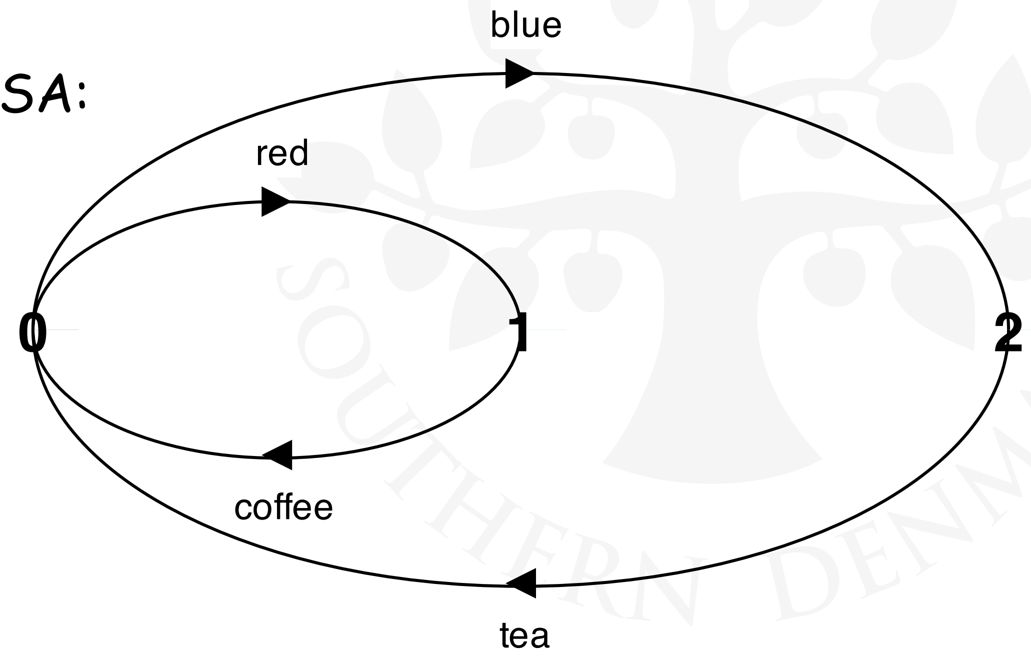

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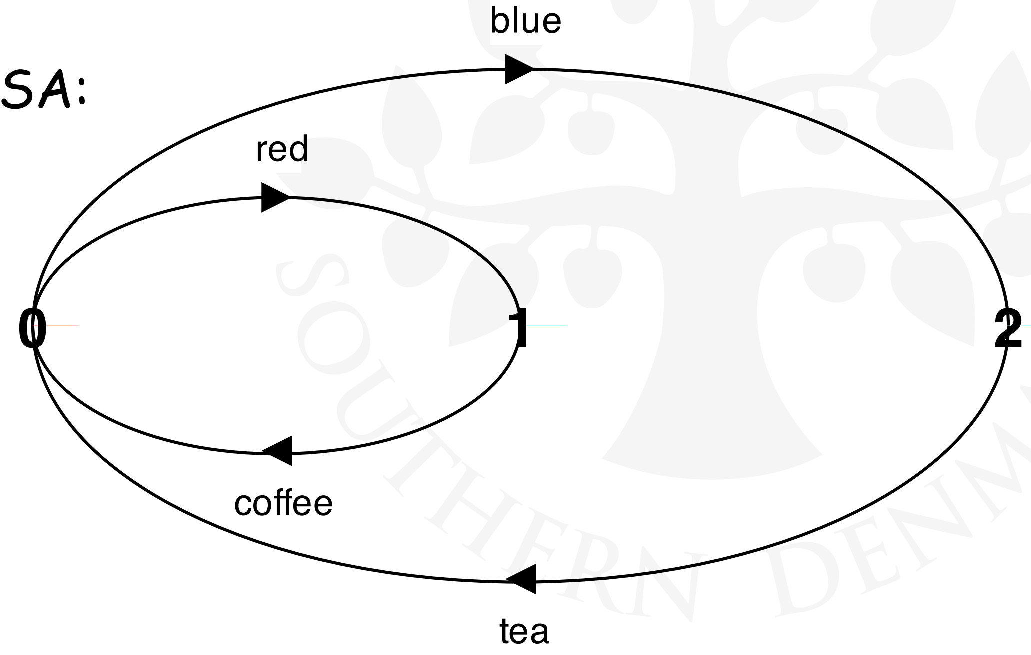

Possible traces?

Non-deterministic choice

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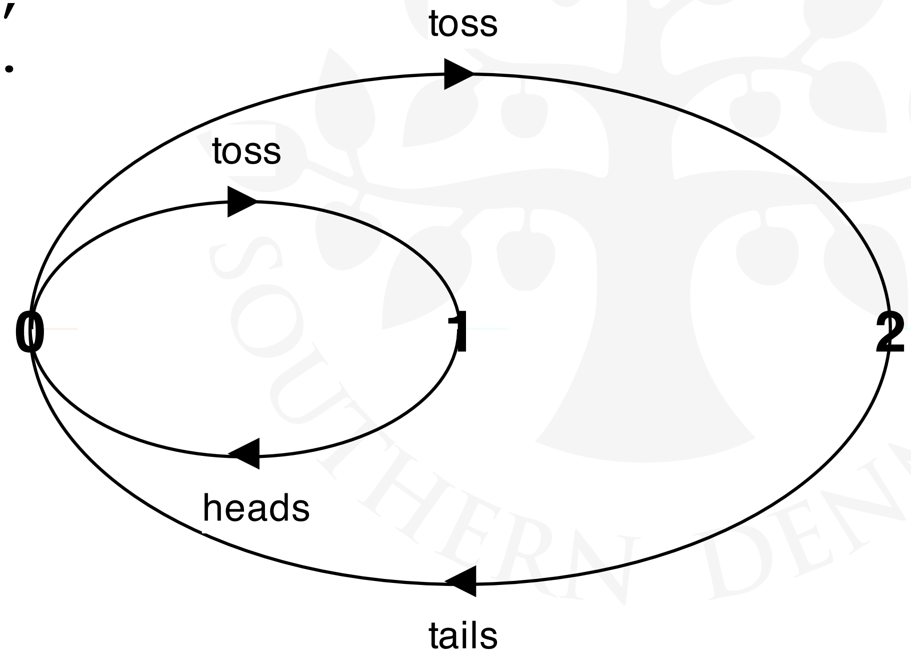

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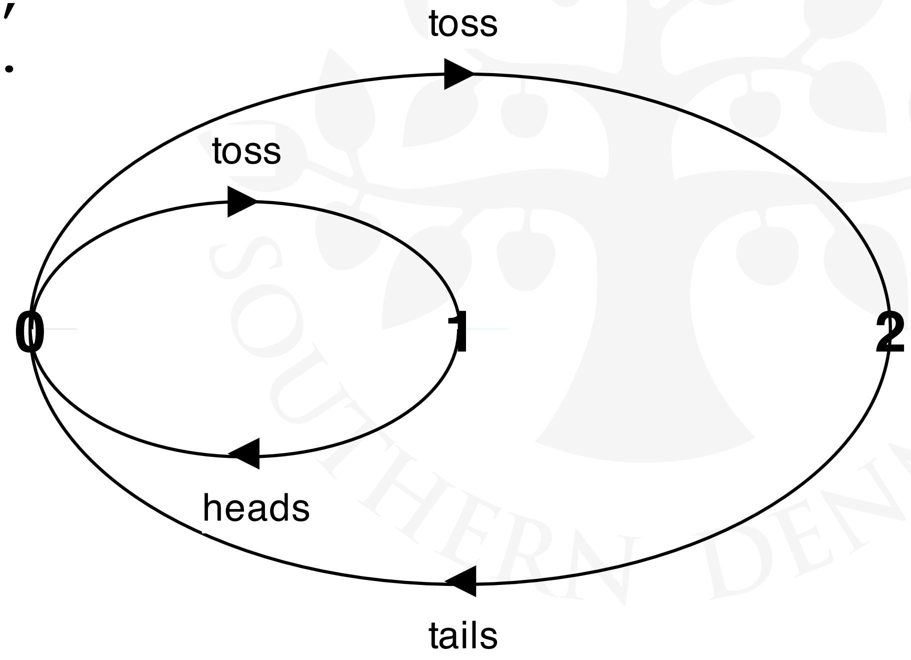

Example: Modelling unreliable communication channel

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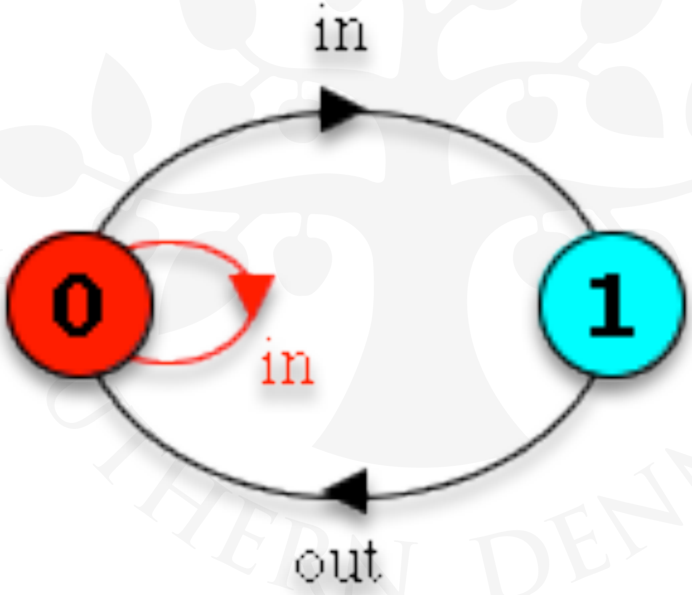

FSP - indexed processes and actions

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

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Define then Use (as in programming languages)

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Define then Use (as in programming languages)

Could we have made this process w/o using the indices?

FSP - indexed processes and actions

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

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       ).
```

...or...:

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

Indices (cont'd)

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

BUFF = (in[0]->out[0]->BUFF
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```

LTS?

Indices (cont’d)

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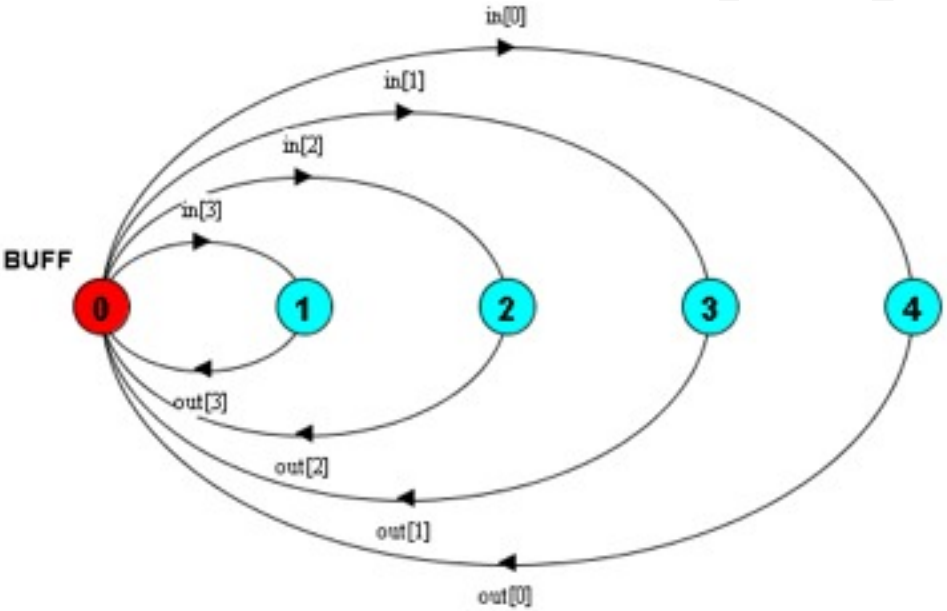
LTS?



FSP - indexed processes and actions (cont’d)

```
BUFF = (in[i:0..3]->out[i]-> BUFF).
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FSP - indexed processes and actions (cont'd)

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

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BUFF        = (in[i:0..3]->OUT[i]),
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FSP - indexed processes and actions (cont'd)

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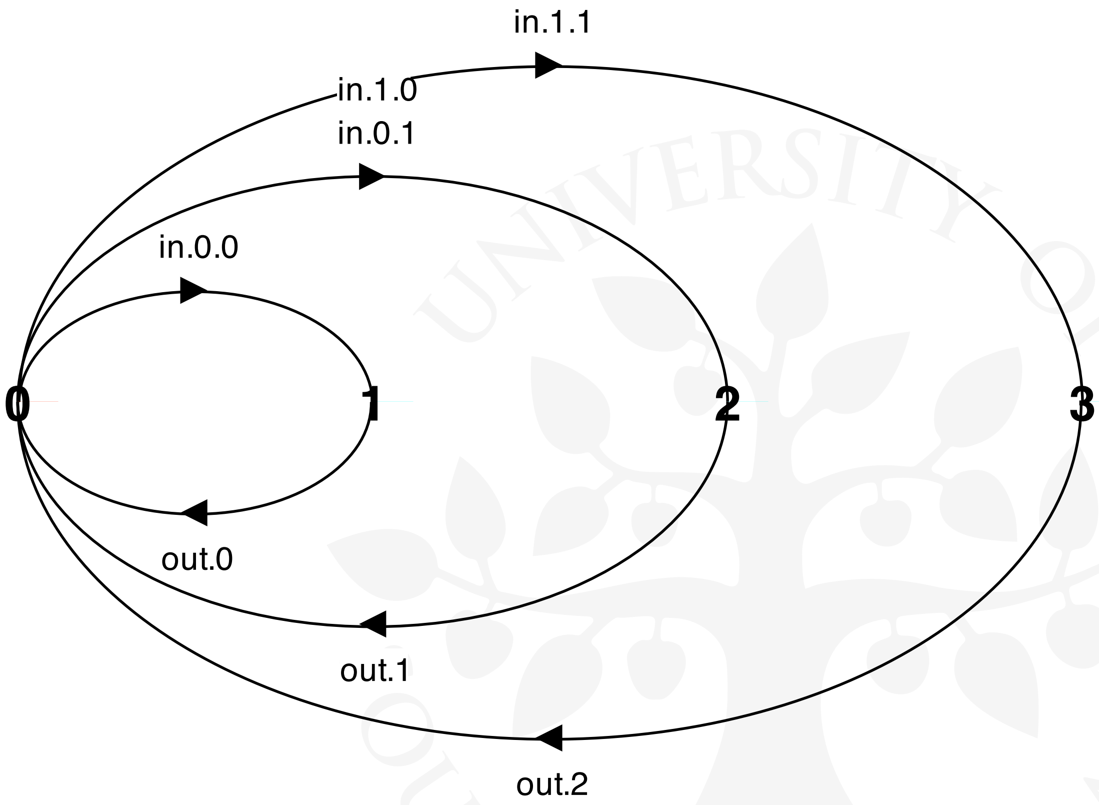
FSP - constant & addition

index expressions to model calculation:



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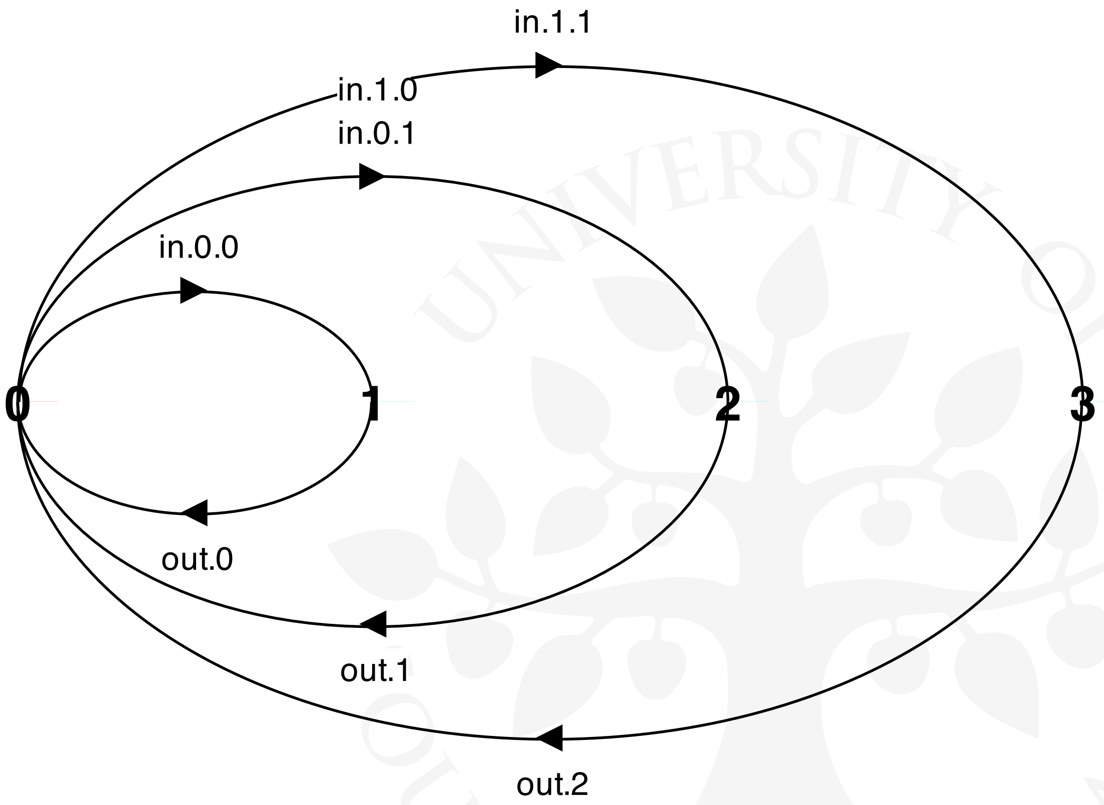

```
const N = 1

SUM          = (in[a:0..N][b:0..N]->TOTAL[a+b]),
TOTAL[s:0..2*N] = (out[s]->SUM).
```

FSP - constant & addition

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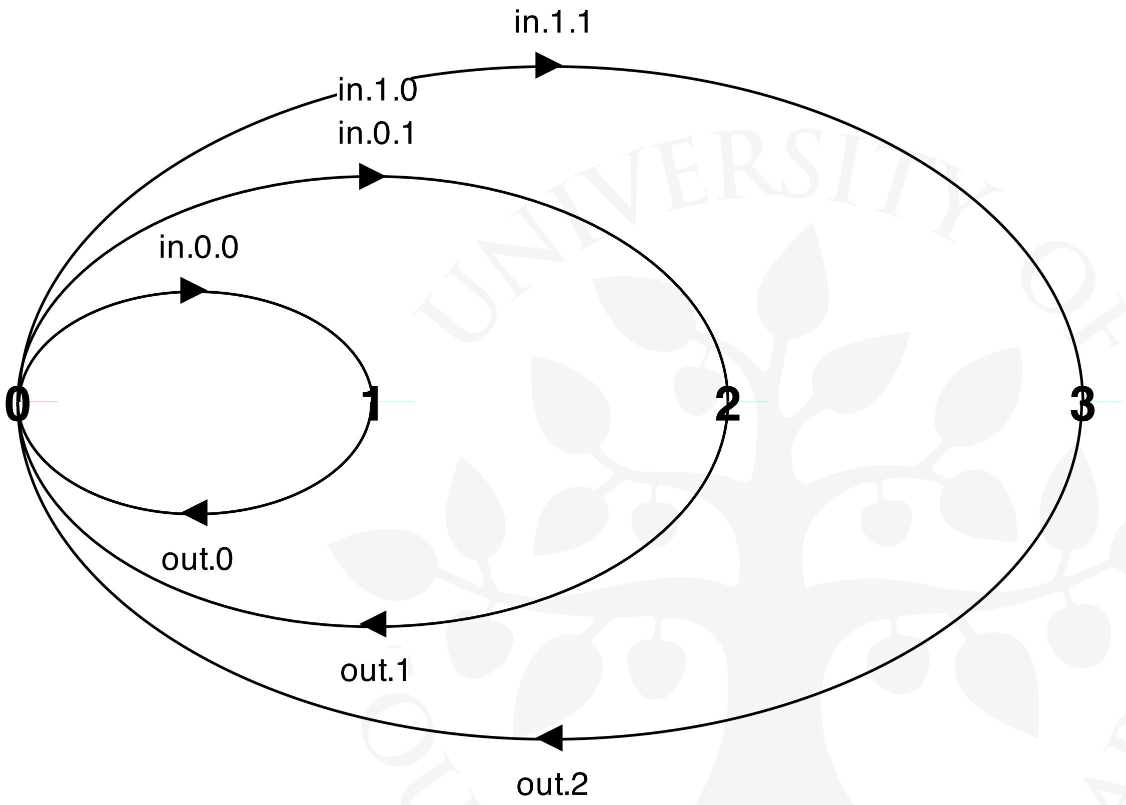

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FSP - constant & range declaration

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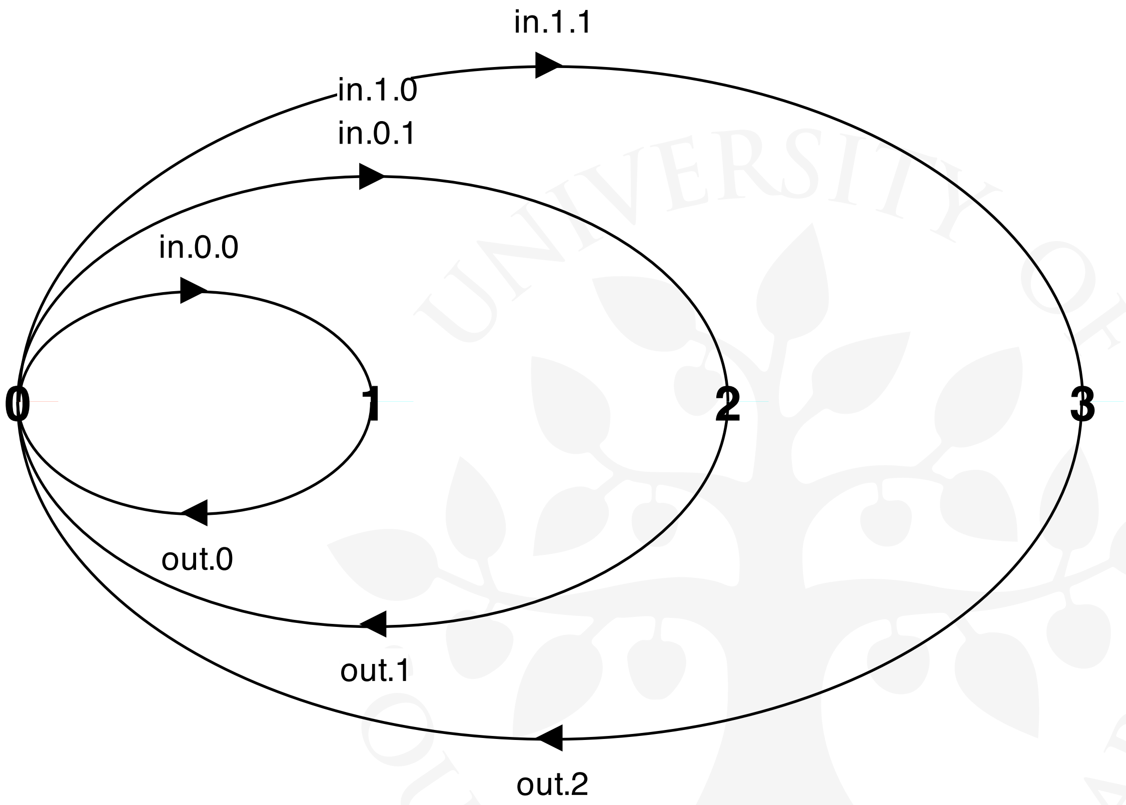

```
const N = 1
range T = 0..N
range R = 0..2*N

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

FSP - guarded actions

The choice (**when B x -> P | y -> 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.

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

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LTS?

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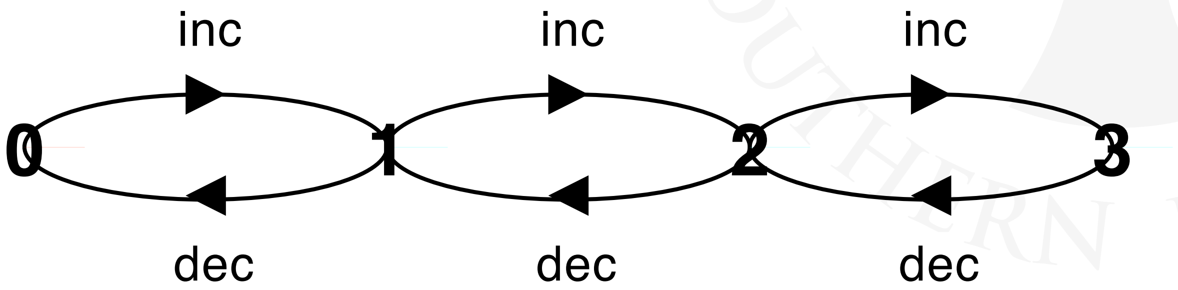

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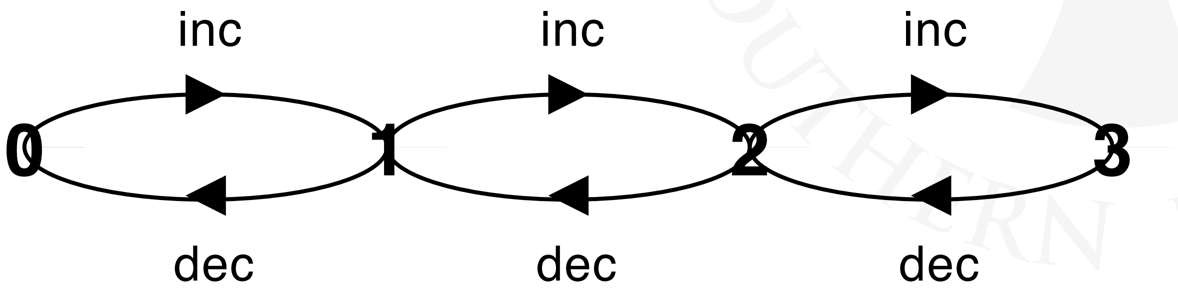

Could we have made this process w/o using the guards?

FSP - guarded actions

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

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```
COUNTDOWN (N=3)   = (start->COUNTDOWN[N]),
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FSP - guarded actions

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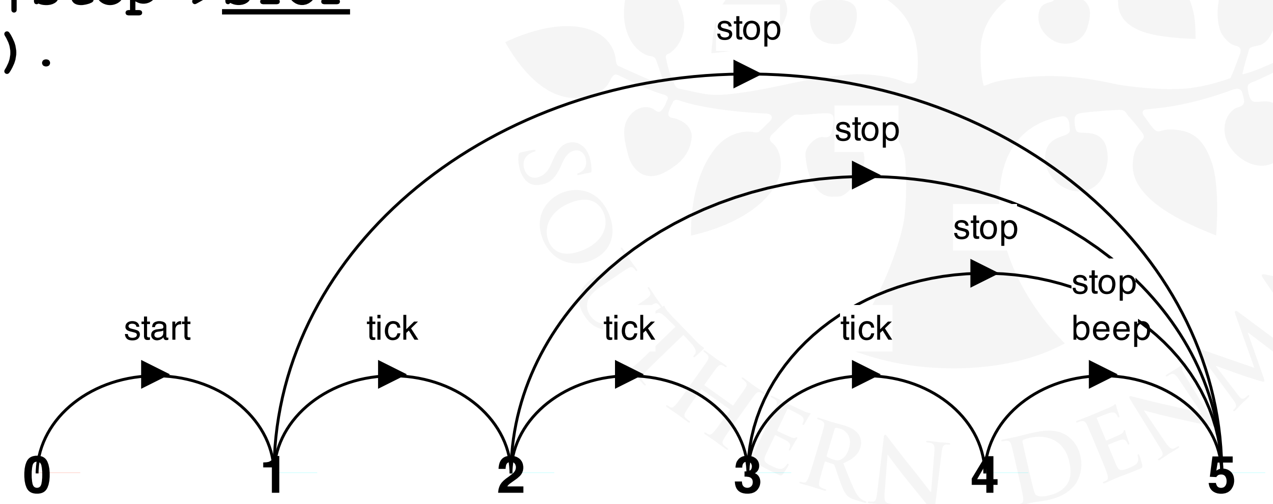
```



FSP - guarded actions

What is the following FSP process equivalent to?

```
const False = 0
P = (when (False) do_anything->P).
```

FSP - guarded actions

What is the following FSP process equivalent to?

```
const False = 0
P = (when (False) do_anything->P).
```

Answer:

```
STOP
```

FSP - process alphabets

The **alphabet** of a process is the set of actions in which it can engage.

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```
WRITER = (write[1]->write[3]->WRITER)
         +{write[0..3]}.
```

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```
WRITER = (write[1]->write[3]->WRITER)
         +{write[0..3]}.
```

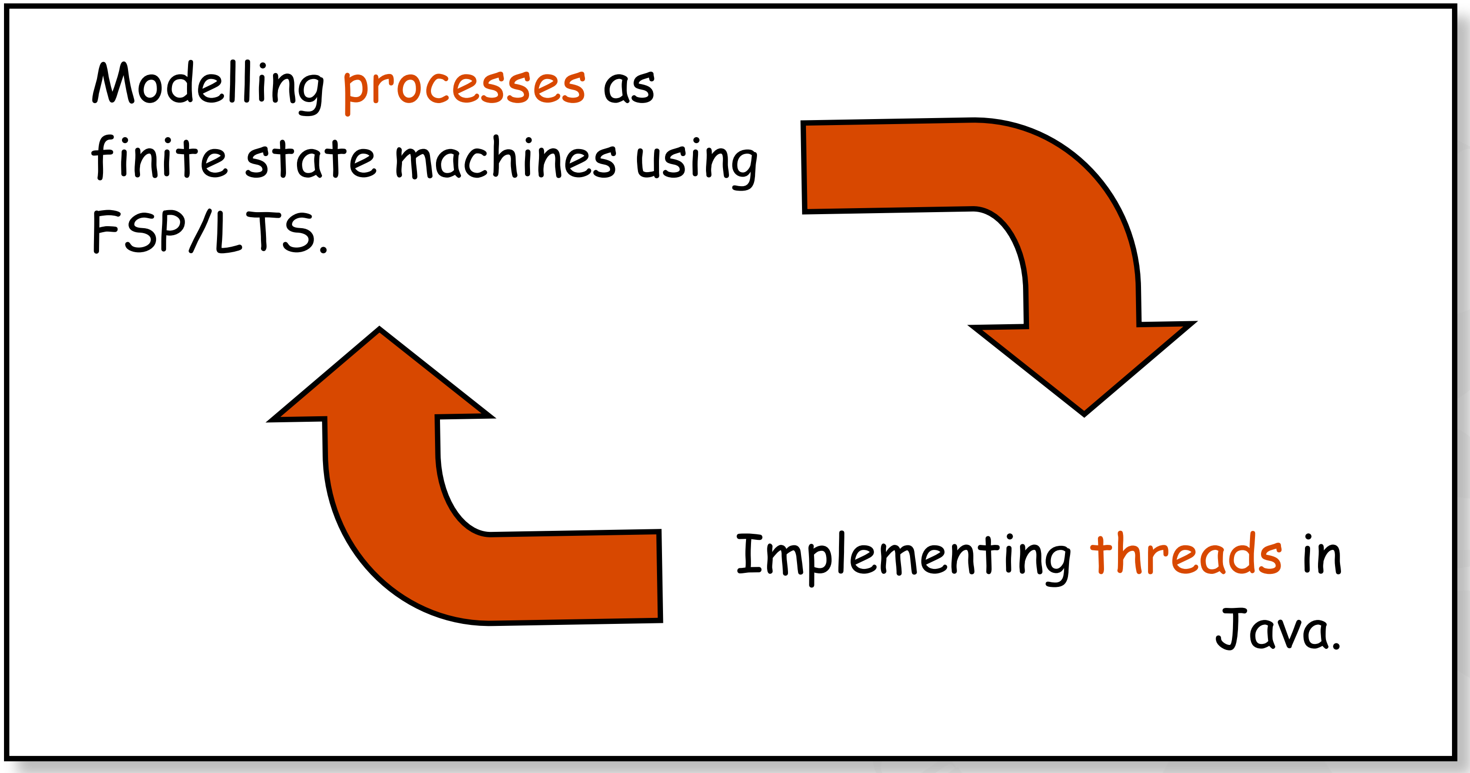
Alphabet of `WRITER` is the set `{write[0..3]}`

(we make use of alphabet extensions in later chapters)

Practice

Threads in Java

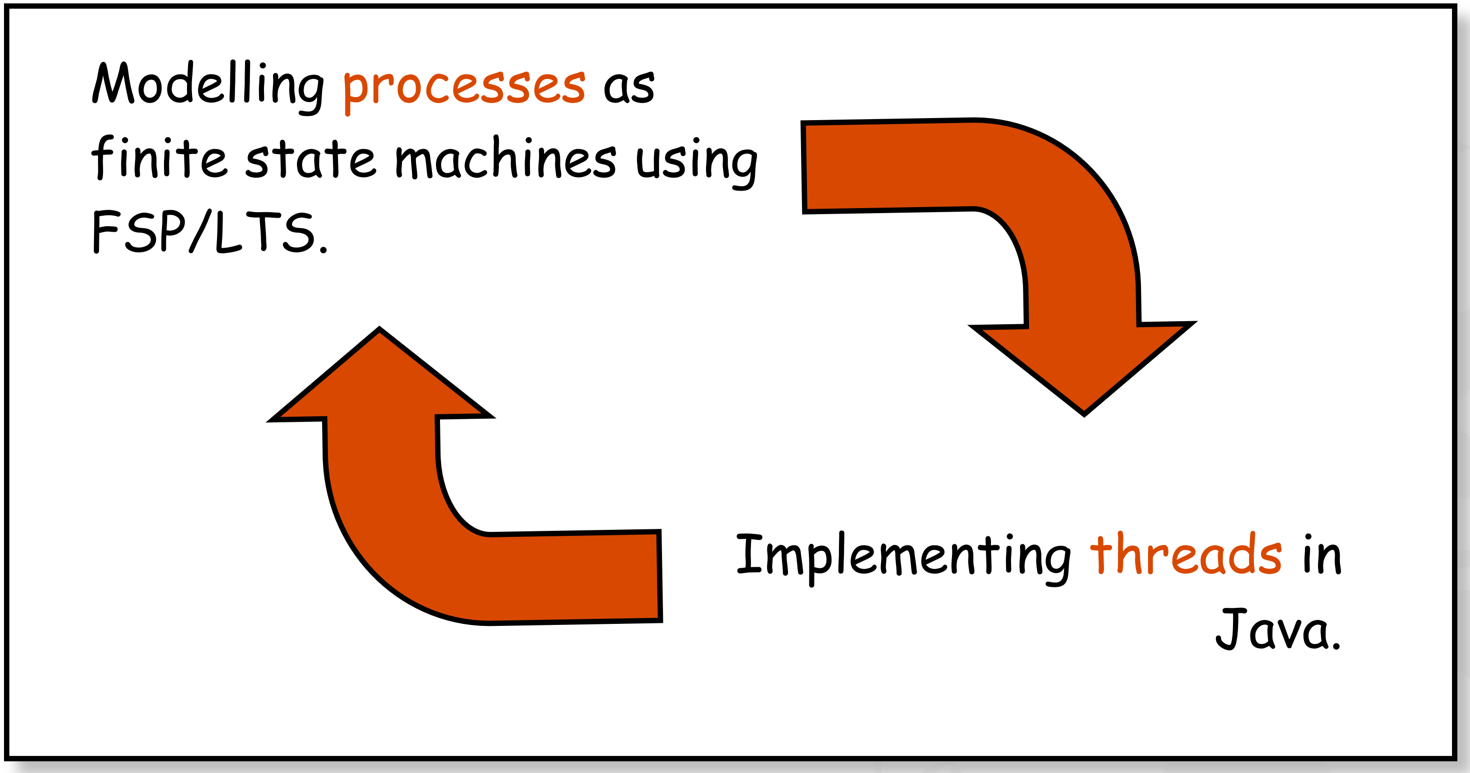
2.2 Implementing processes



Modelling processes as finite state machines using FSP/LTS.

Implementing threads in Java.

2.2 Implementing processes



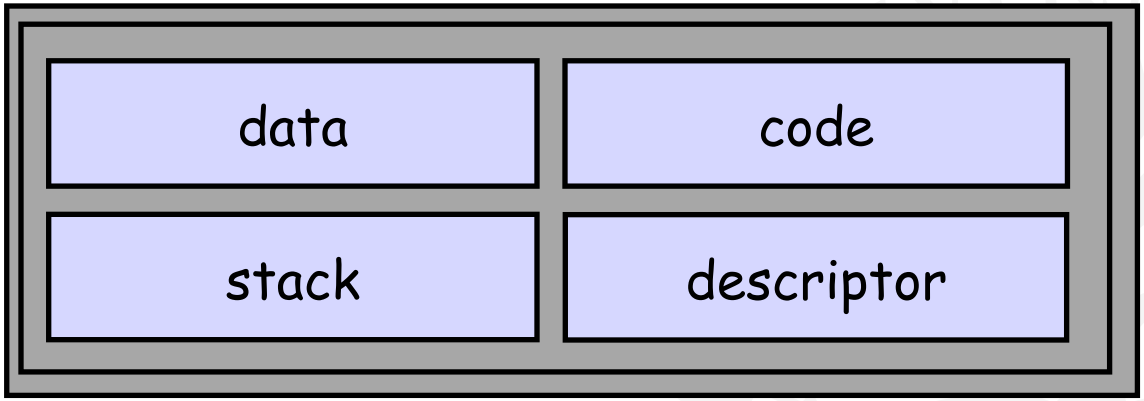
Modelling processes as finite state machines using FSP/LTS.

Implementing threads in Java.

Note: to avoid confusion, we use the term **process** when referring to the models, and **thread** when referring to the implementation in Java.

One Process

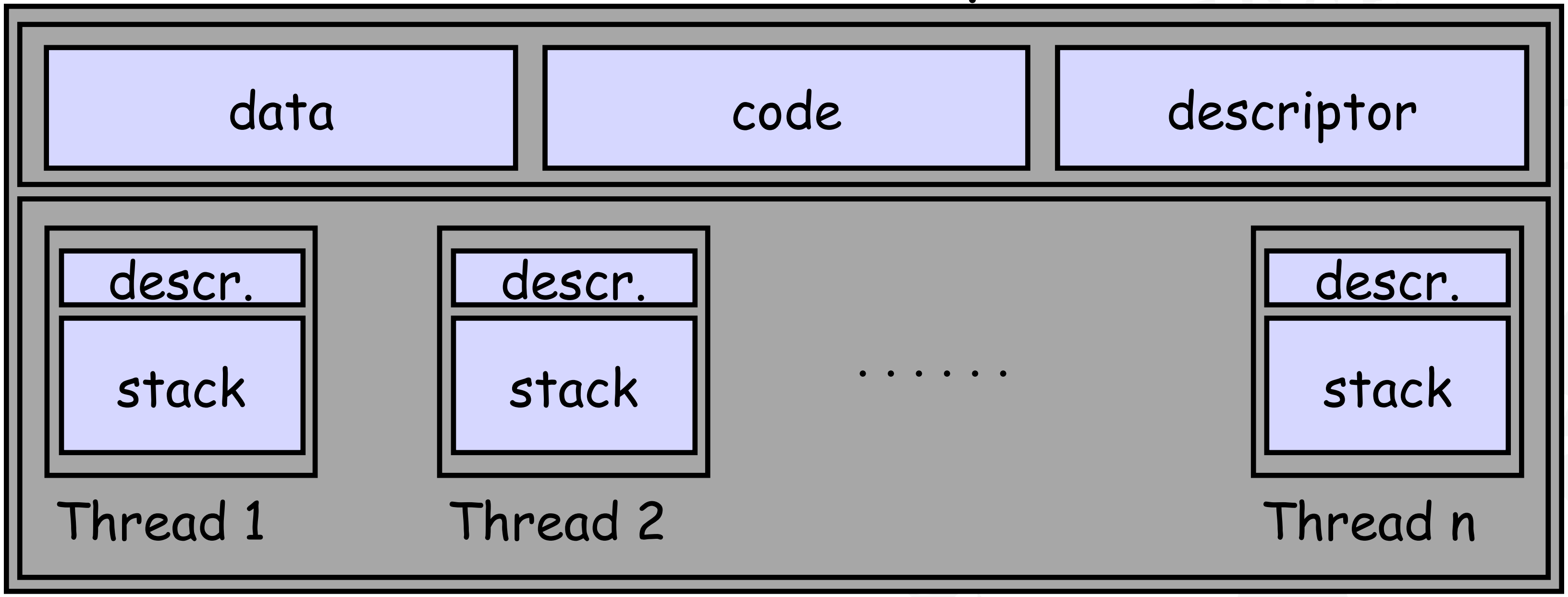
- Process:



Data:	The heap (global, heap allocated data)
Code:	The program (bytecode)
Stack:	The stack (local data, call stack)
Descriptor:	Program counter, stack pointer, …

Implementing processes - the OS view

A multi-threaded process



A (heavyweight) process in an operating system is represented by its code, data and the state of the machine registers, given in a descriptor. In order to support multiple (lightweight) **threads of control**, it has multiple stacks, one for each thread.

Threads in Java

A Thread class manages a single sequential thread of control.
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```
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     public void run() {
          //......
     }
}
```

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Thread x = new MyThread();
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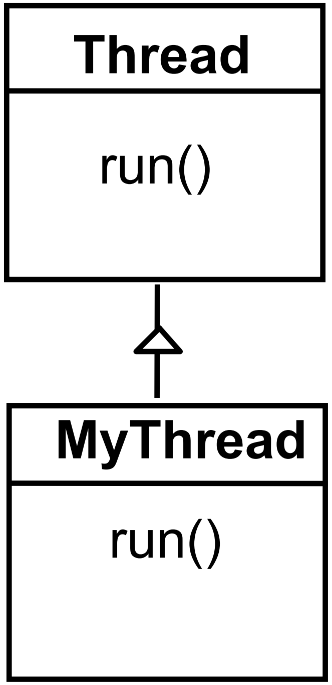

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     public void run() {
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     }
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Threads in Java (cont'd)

Since Java does not permit multiple inheritance, we often implement the **run()** method in a class not derived from Thread but from the interface Runnable.

Threads in Java (cont'd)

Since Java does not permit multiple inheritance, we often implement the **run()** method in a class not derived from Thread but from the interface Runnable.

```
public interface Runnable {
    public abstract void run();
}

class MyRun implements Runnable {
    public void run() {
        //......
    }
}
```

Threads in Java (cont'd)

Since Java does not permit multiple inheritance, we often implement the **run()** method in a class not derived from Thread but from the interface Runnable.

```
public interface Runnable {
    public abstract void run();
}

class MyRun implements Runnable {
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        //......
    }
}
```

```
Thread x = new Thread(new MyRun());
```

Threads in Java (cont'd)

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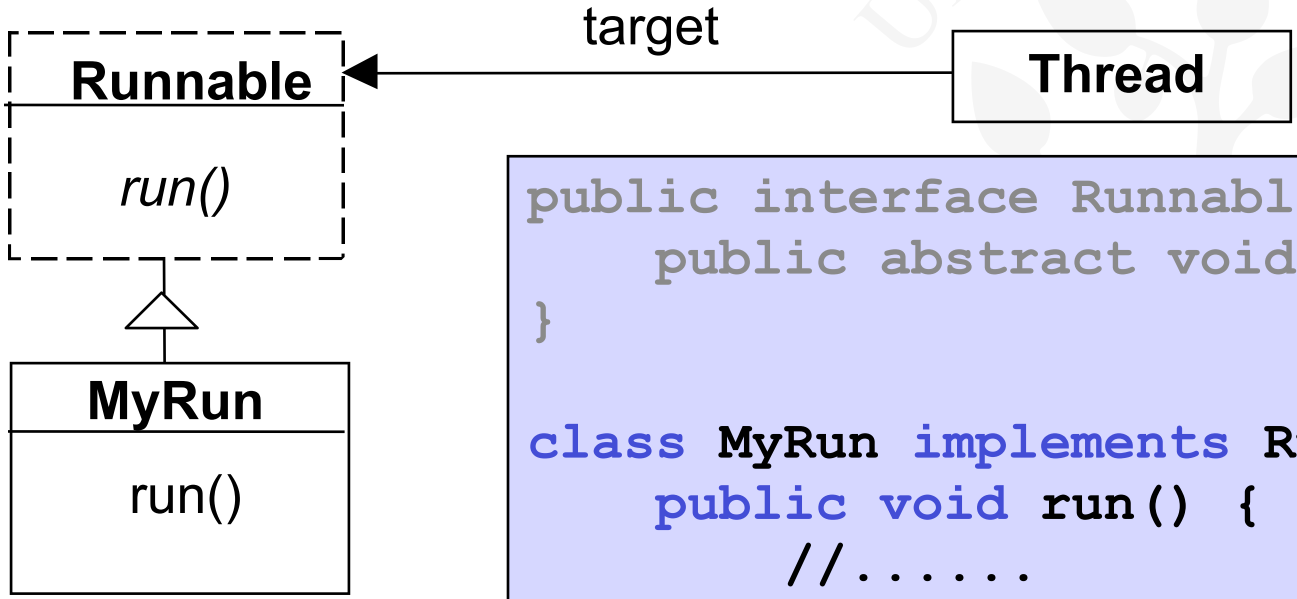

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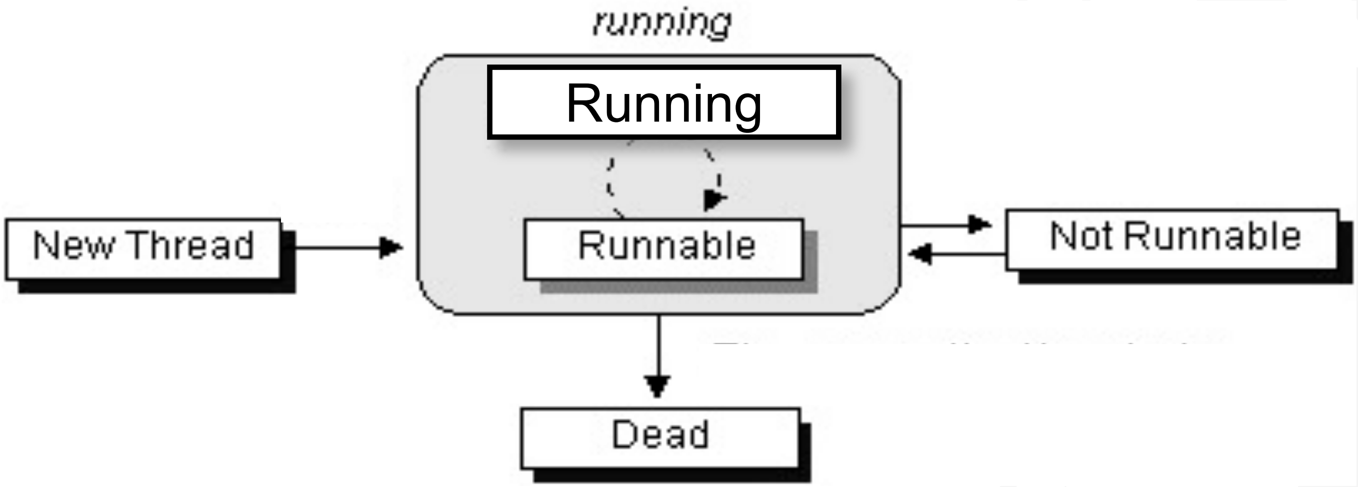
Thread x = new Thread(new MyRun());
```

Thread Life-Cycle

Java Thread Life-Cycle:



Thread Life-Cycle

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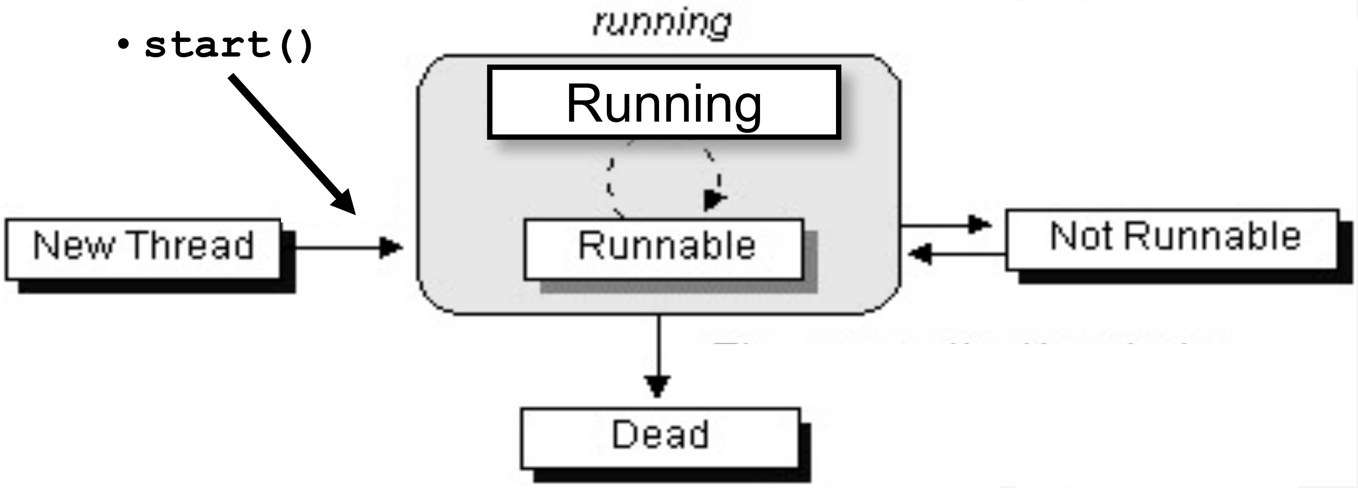

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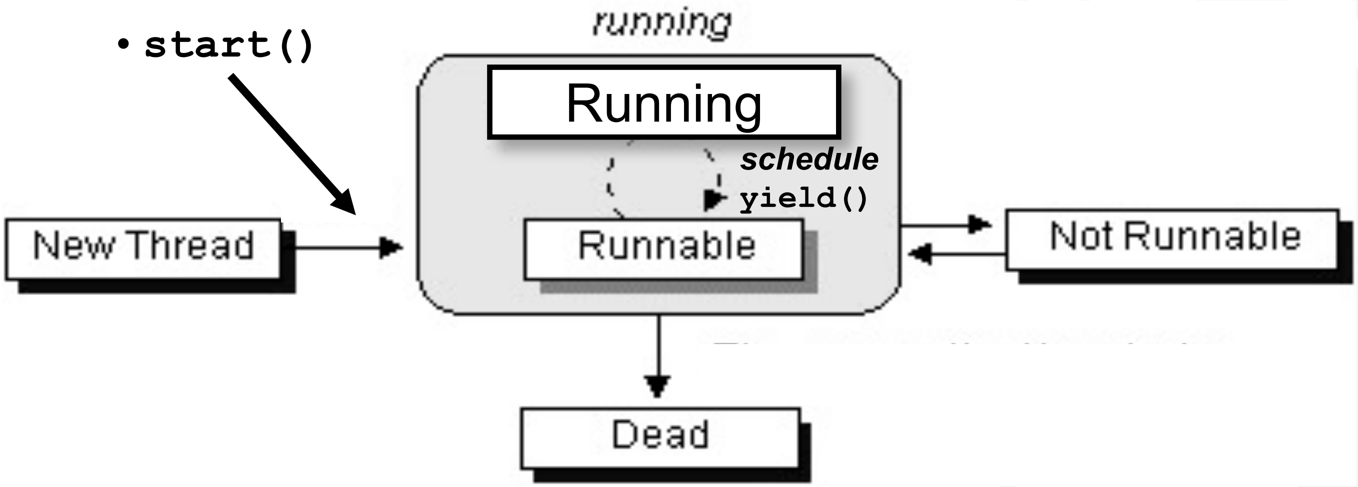

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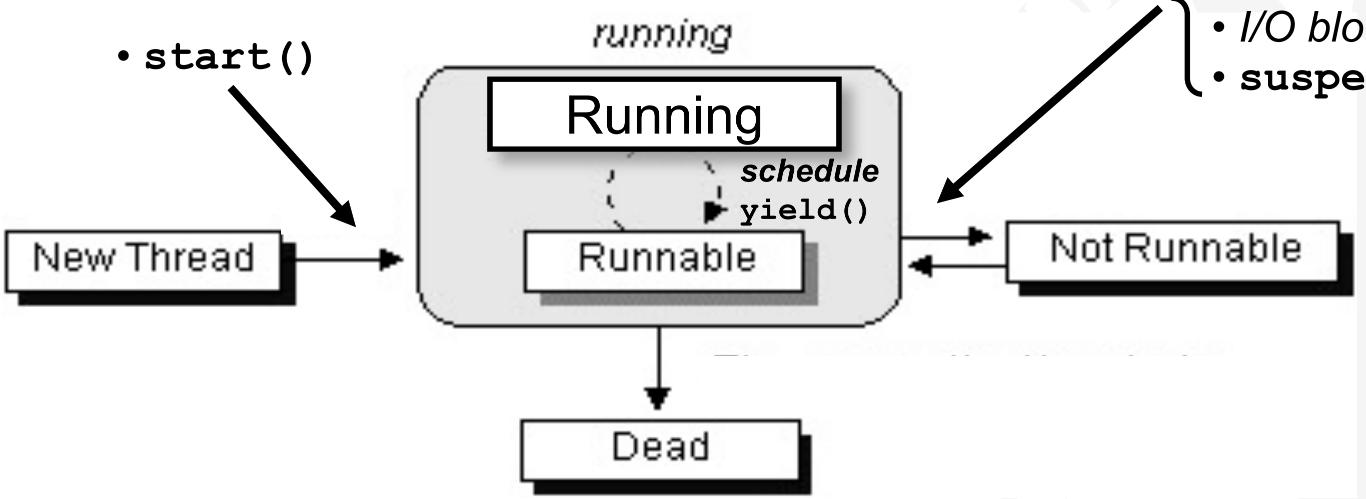
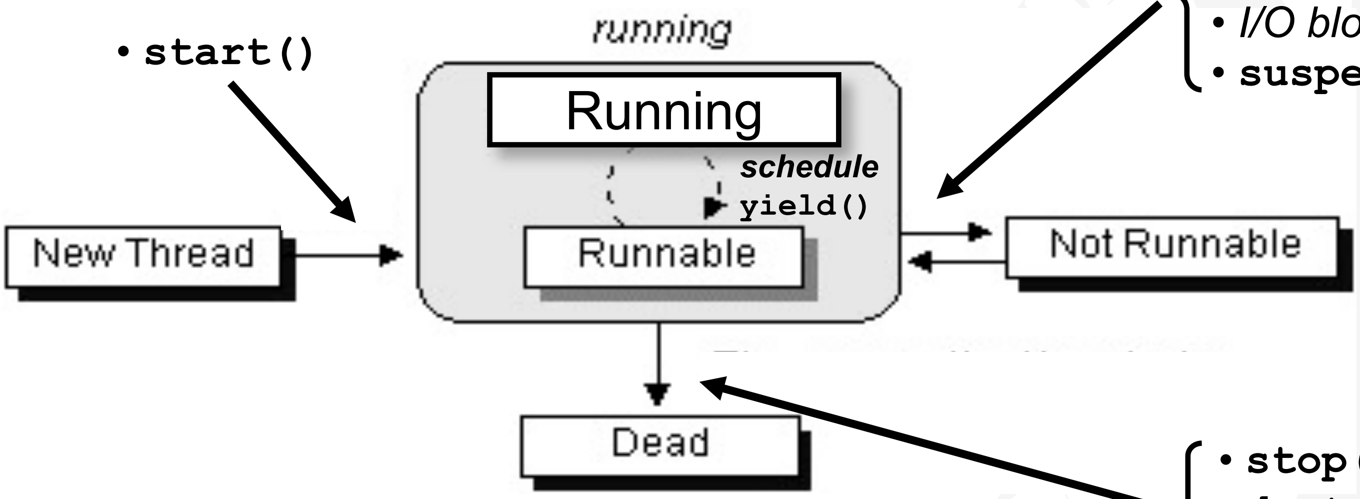


• `sleep(k`$_{msec}$`)`	*wakeup*
• `wait()`	`notify()`
• *I/O block*	*unblock*
• `suspend()`	`resume()`

Thread Life-Cycle

Java Thread Life-Cycle:



- **start()**

running

Running

schedule

yield()

New Thread

Runnable

Not Runnable

Dead

• **sleep(k_{msec})**	*wakeup*
• **wait()**	**notify()**
• *I/O block*	*unblock*
• **suspend()**	**resume()**

- **stop()**
- **destroy()**
- **run()** ***terminates***

Example: Countdown timer

Model <-> Impl.

CountDown timer example

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

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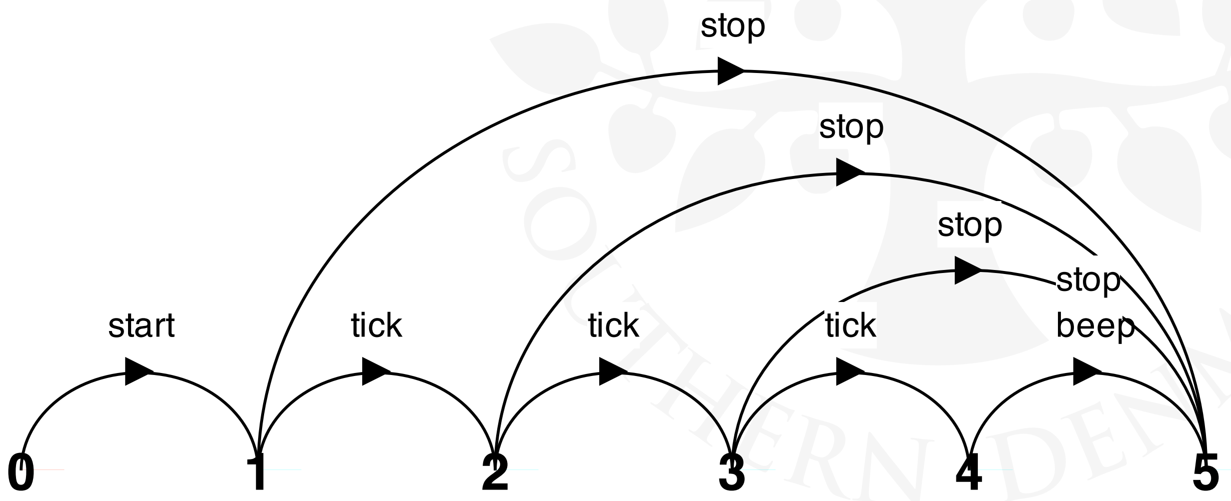

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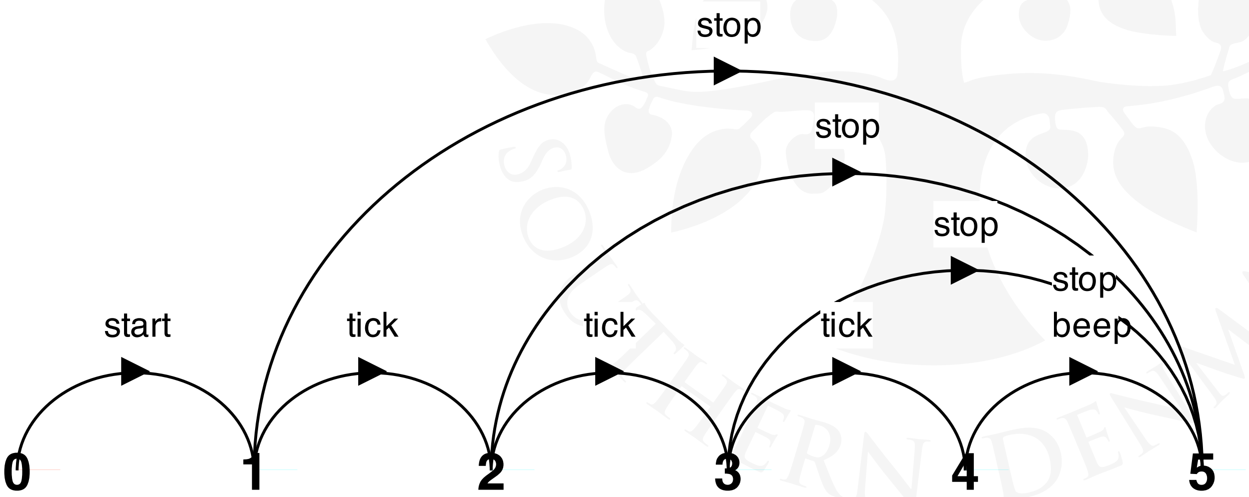
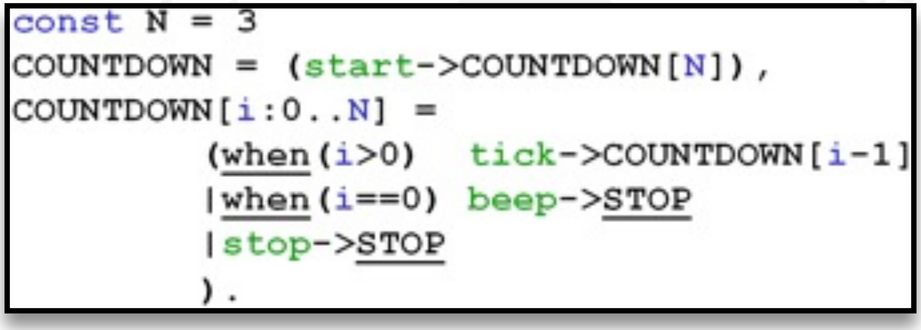


Implementation in Java?

CountDown class

```
public class CountDown implements Runnable {
    Thread counter;
    int i;
    final static int N = 3;
    public void run()       { ... }
    public void start()     { ... }
    public void stop()      { ... }
    protected void tick()   { ... }
    protected void beep()   { ... }
}
```



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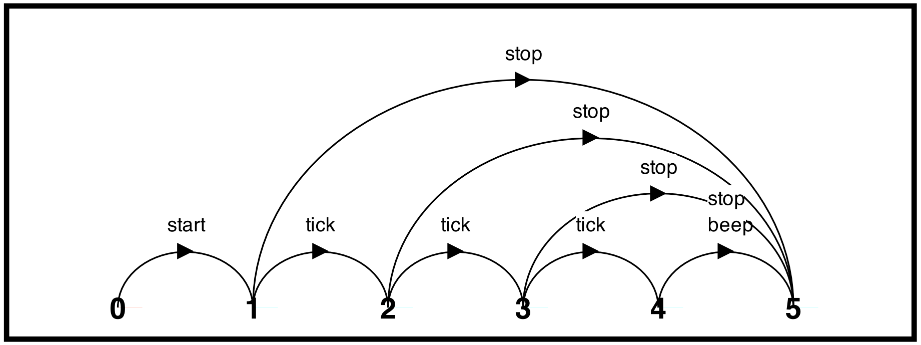

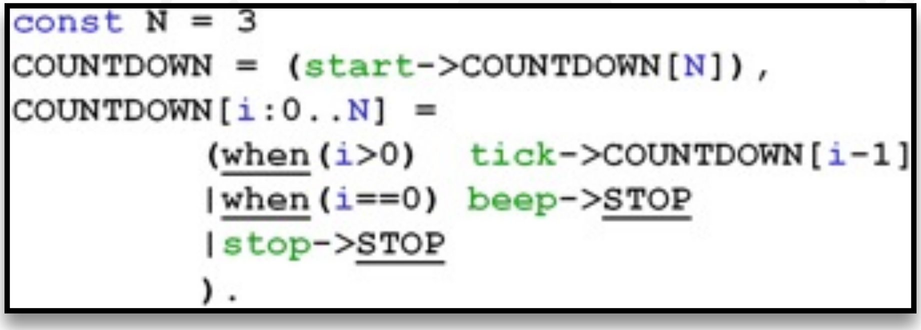

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CountDown class - start(), stop() and run()

COUNTDOWN Model

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COUNTDOWN Model

```
start -> CountDown[N]
```

CountDown class - start(), stop() and run()

```
public void start() {
   counter = new Thread(this);
   i = N; counter.start();
}
```

COUNTDOWN Model

```
start -> CountDown[N]
```

CountDown class - start(), stop() and run()

```
public void start() {
   counter = new Thread(this);
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COUNTDOWN Model

```
start -> CountDown[N]

stop -> STOP
```

CountDown class - start(), stop() and run()

```
public void start() {
   counter = new Thread(this);
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public void stop() {
   counter = null;
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start -> CountDown[N]


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COUNTDOWN Model

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start -> CountDown[N]

stop -> STOP
```

COUNTDOWN[i] process

CountDown class - start(), stop() and run()

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  }

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    counter = null;
  }

  public void run() {
```

COUNTDOWN Model

```
start -> CountDown[N]


stop -> STOP


COUNTDOWN[i] process
```

CountDown class - start(), stop() and run()

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  }

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```

COUNTDOWN Model

start -> CountDown[N]

stop -> *STOP*

COUNTDOWN[i] process

recursion as a while loop

CountDown class - start(), stop() and run()

```
public void start() {
   counter = new Thread(this);
   i = N; counter.start();
}

public void stop() {
   counter = null;
}

public void run() {
   while(true) {
```

COUNTDOWN Model

`start -> CountDown[N]`

`stop -> STOP`

`COUNTDOWN[i]` process

`recursion` as a `while` loop

CountDown class - start(), stop() and run()

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}

public void stop() {
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}

public void run() {
   while(true) {
     if (i>0)  { tick(); --i; }
```

COUNTDOWN Model

start -> CountDown[N]

stop -> *STOP*

COUNTDOWN[i] process

recursion as a while loop

when(i>0) tick -> CD[i-1]

CountDown class - start(), stop() and run()

```
  public void start() {
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  }

  public void stop() {
     counter = null;
  }

  public void run() {
     while(true) {
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       if (i==0) { beep(); return;}
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COUNTDOWN Model

```
start -> CountDown[N]
```

```
stop -> STOP
```

COUNTDOWN[i] process

recursion as a while loop

```
when(i>0)  tick -> CD[i-1]
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}

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      if (i==0) { beep(); return;}
      if (counter == null) return;
```

COUNTDOWN Model

```
start -> CountDown[N]

stop -> STOP
```

COUNTDOWN[i] process

recursion as a while loop

```
when(i>0) tick -> CD[i-1]
when(i==0)beep -> STOP
stop->STOP
```

CountDown class - start(), stop() and run()

```
public void start() {
   counter = new Thread(this);
   i = N; counter.start();
}

public void stop() {
   counter = null;
}

public void run() {
   while(true) {
      if (i>0)  { tick(); --i; }
      if (i==0) { beep(); return;}
      if (counter == null) return;
   }
}
```

COUNTDOWN *Model*

```
start -> CountDown[N]

stop -> STOP
```

`COUNTDOWN[i]` process

```
recursion as a while loop
when(i>0) tick -> CD[i-1]
when(i==0)beep -> STOP
stop->STOP
```

STOP ~ `run()` *terminates*

CountDown class – the output actions: tick() and beep()

```
protected void tick() {
    <<emit tick sound>>
    try {
        Thread.sleep(1000);
    } catch(InterruptedException iex){
        // ignore (in this toy-example)
    }
}

protected void beep() {
    <<emit beep sound>>
}
```

Summary

Concepts

- process - unit of concurrency, execution of a program

Models

- LTS (Labelled Transition System) to model processes as state machines - sequences of atomic actions
- FSP (Finite State Process) to specify processes using prefix “->”, choice ” | ” and recursion

Practice

- Java threads to implement processes
- Thread lifecycle
(created, running, runnable, non-runnable, terminated)

Near Future

Lecture Tuesday:

- M&K: Chapter 3

Discussion Sections & Study Groups

- Details are in Weekly Note 1