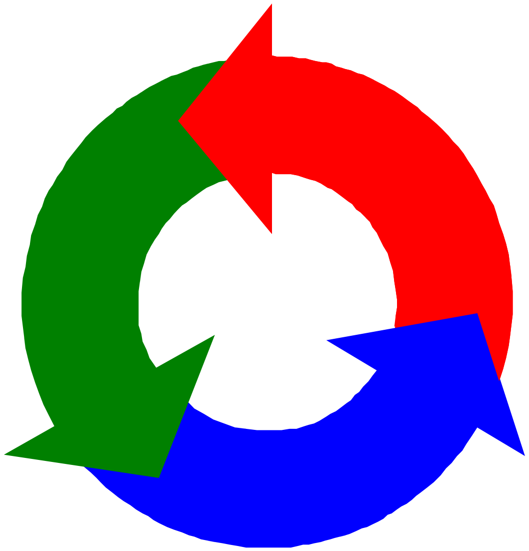
Concurrency

2 – Processes and Threads



Alexandre David

adavid@cs.aau.dk

Credits for the slides:
Claus Brabrand
Jeff Magee & Jeff Kramer

Concurrent Processes

We structure complex systems as sets of simpler activities, each represented as a **sequential process**

Processes can be **concurrent**

Designing concurrent software:

- **complex** *and* **error prone**

We need rigorous engineering approach!

***Concept*: process ~ sequence of actions**

***Model*: process ~ Finite State Processes (FSP)**

***Practice*: process ~ Java thread**

Processes and Threads

Concepts: *Processes - units of sequential execution*

Models: **Finite State Processes (FSP)**

to model processes as sequences of actions

Labelled Transition Systems (LTS)

to analyse, display, and animate behaviour

Abstract *model of execution*

Practice: *Java threads*

Modeling Processes

Models are described using state machines, known as **Labelled Transition Systems** *(***LTS***)*

These are described textually as **Finite State Processes** *(***FSP***)*

Analysed/Displayed by the **LTS Analyser** *(***LTSA***)*

- ♦ ***LTS*** *- graphical form*
- ♦ ***FSP*** *- algebraic form*

FSP - STOP

STOP *is the inactive process, doing absolutely nothing.*

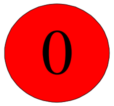
FSP:

```
INACTIVE = STOP.
```

INACTIVE state machine

(terminating process)

LTS:



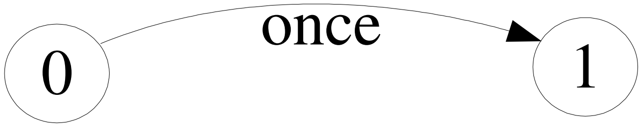
FSP – Action Prefix

If **x** *is an action and* **P** *a process then* **(x-> P)** *describes a process that initially engages in the action* **x** *and then behaves exactly as described by* **P***.*

FSP:

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

LTS:

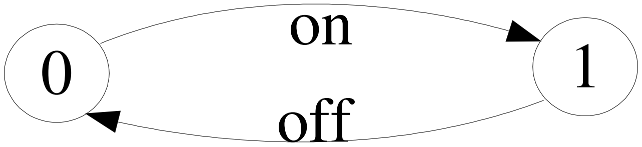


Convention: actions begin with lowercase letters

PROCESSES begin with uppercase letters

Modeling Processes

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



a light switch **LTS**

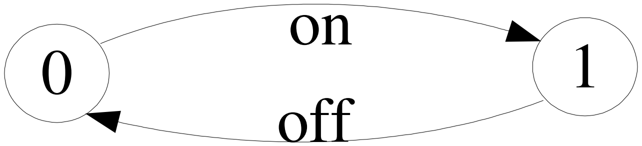
`on->off->on->off->on->off->` …

a sequence of actions or ***trace***

FSP – Action Prefix and Recursion

Repetitive behaviour uses recursion:

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



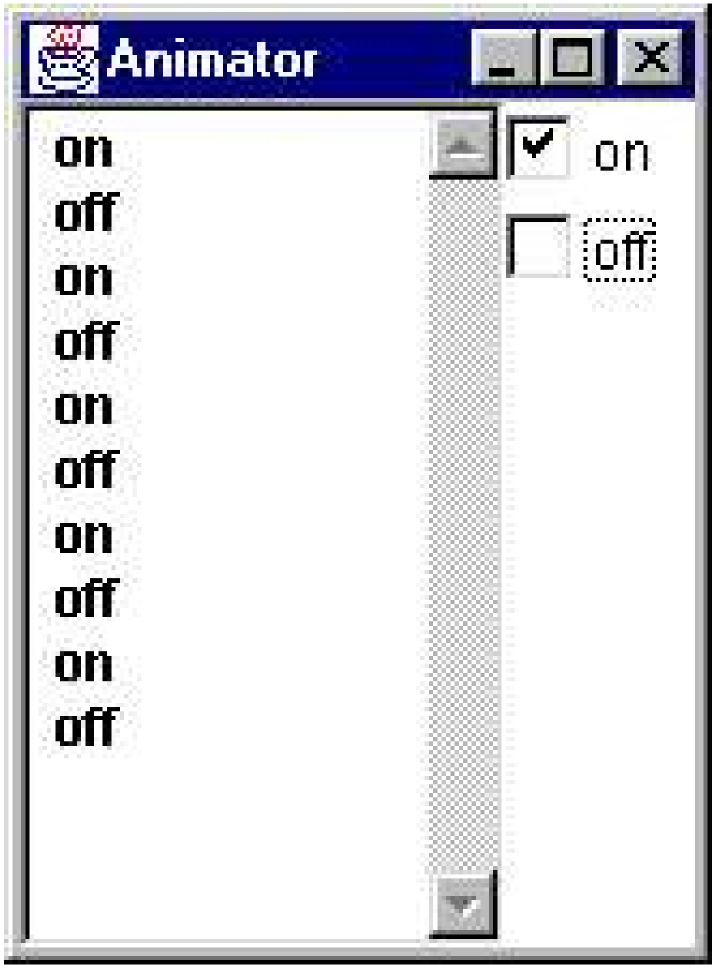
Substituting to get a more succinct definition:

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

Again?:

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

Animation using LTSA



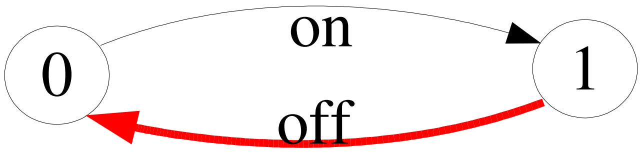
on
off
on
off
on
off
on
off
on
off

☑ 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.

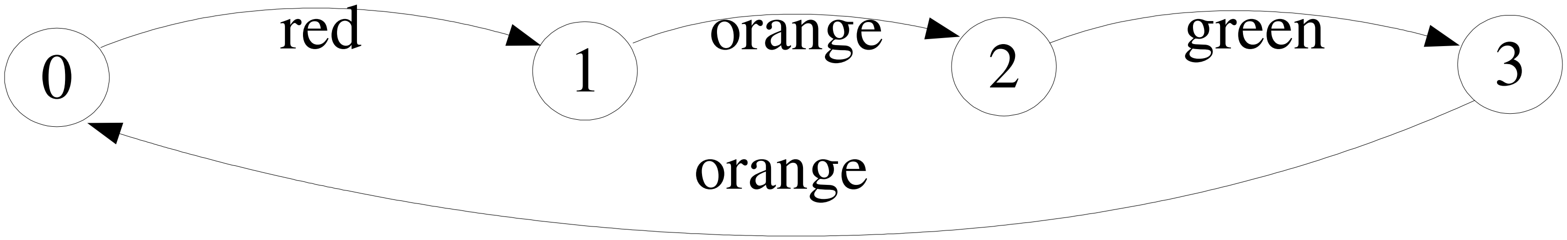


FSP – Action Prefix

FSP model of a traffic light:

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

LTS?



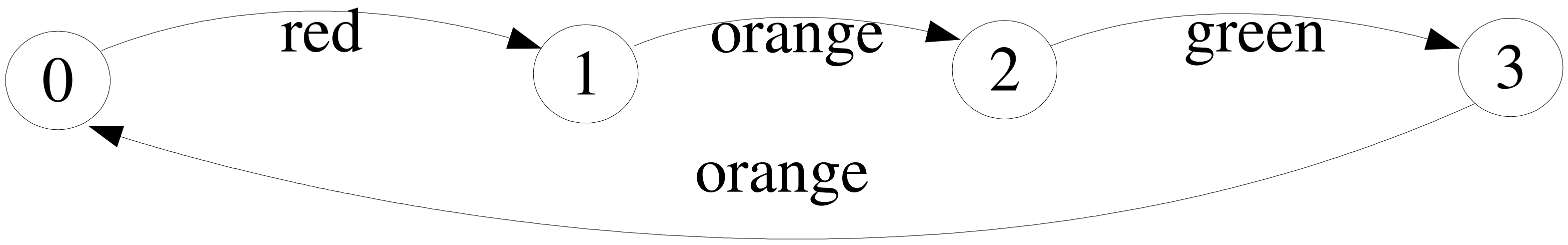
Trace(s)?

FSP – Action Prefix

FSP model of a traffic light:

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

LTS?



Trace(s)?

```
red->orange->green->orange->red->orange->…
```

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 behaviour is described by* **P** *if the first action was* **x**; *and* **Q** *if the first action was* **y**.

Who or what makes the choice?

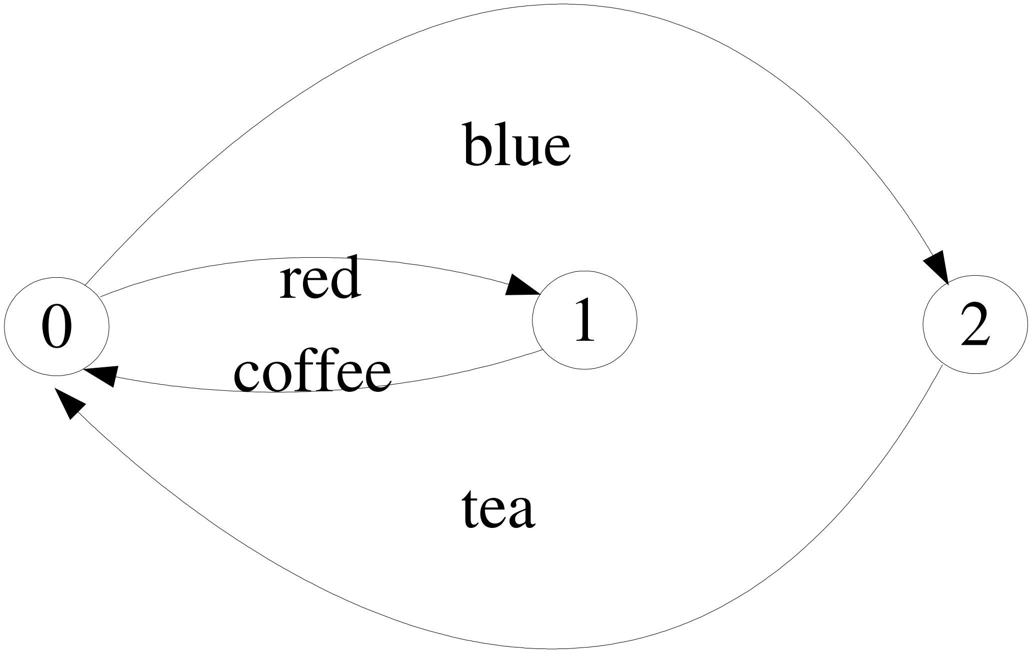
Is there a difference between input and output actions?

FSP - Choice

FSP model of a drinks machine :

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

LTS generated using LTSA:



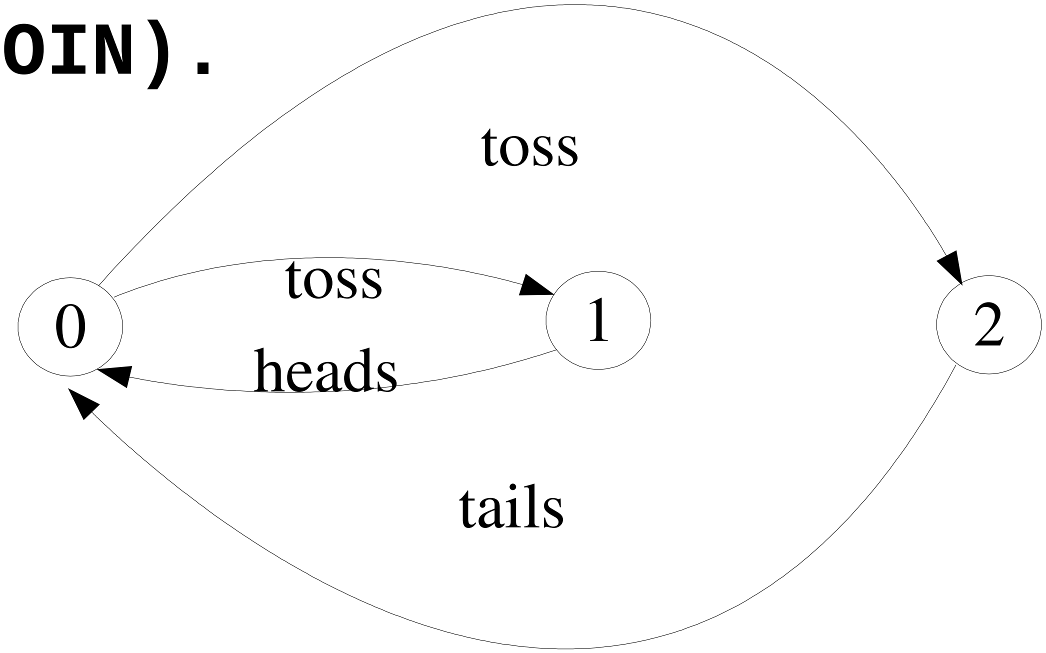
Possible traces?

Non-deterministic Choices

*Process (x-> P | x -> 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.



LTS?

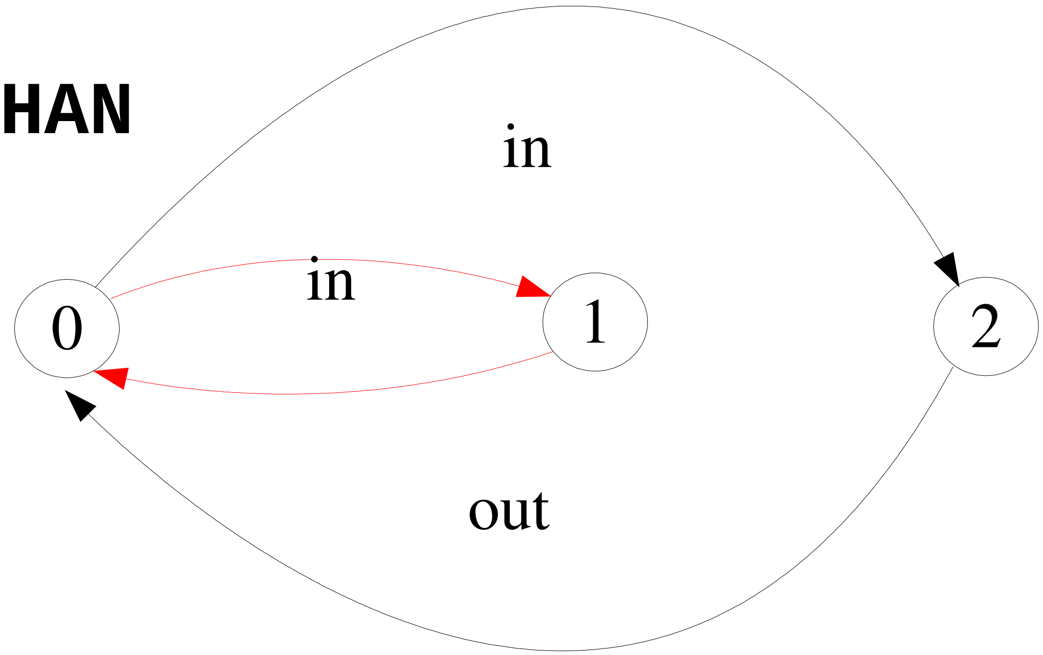
Possible traces?

Example

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:

equivalent to

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

or using a process parameter with default value:

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

Cont.

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

equivalent to

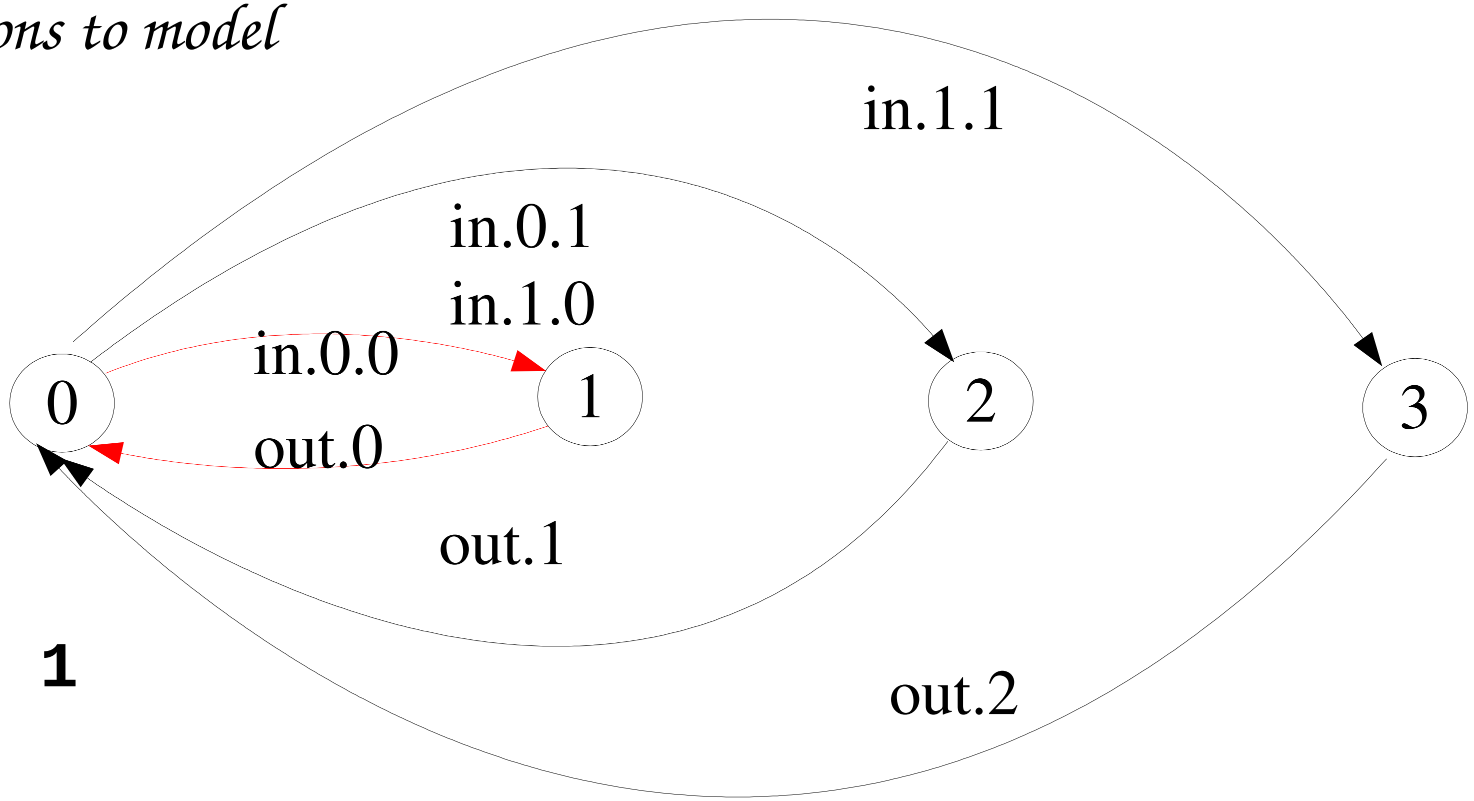
```
BUFF        = (in[i:0..3]->OUT[i]),

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

equivalent to

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

OUT[j:0..3] = (out[j]->BUFF).
```

FSP – Constant and Addition

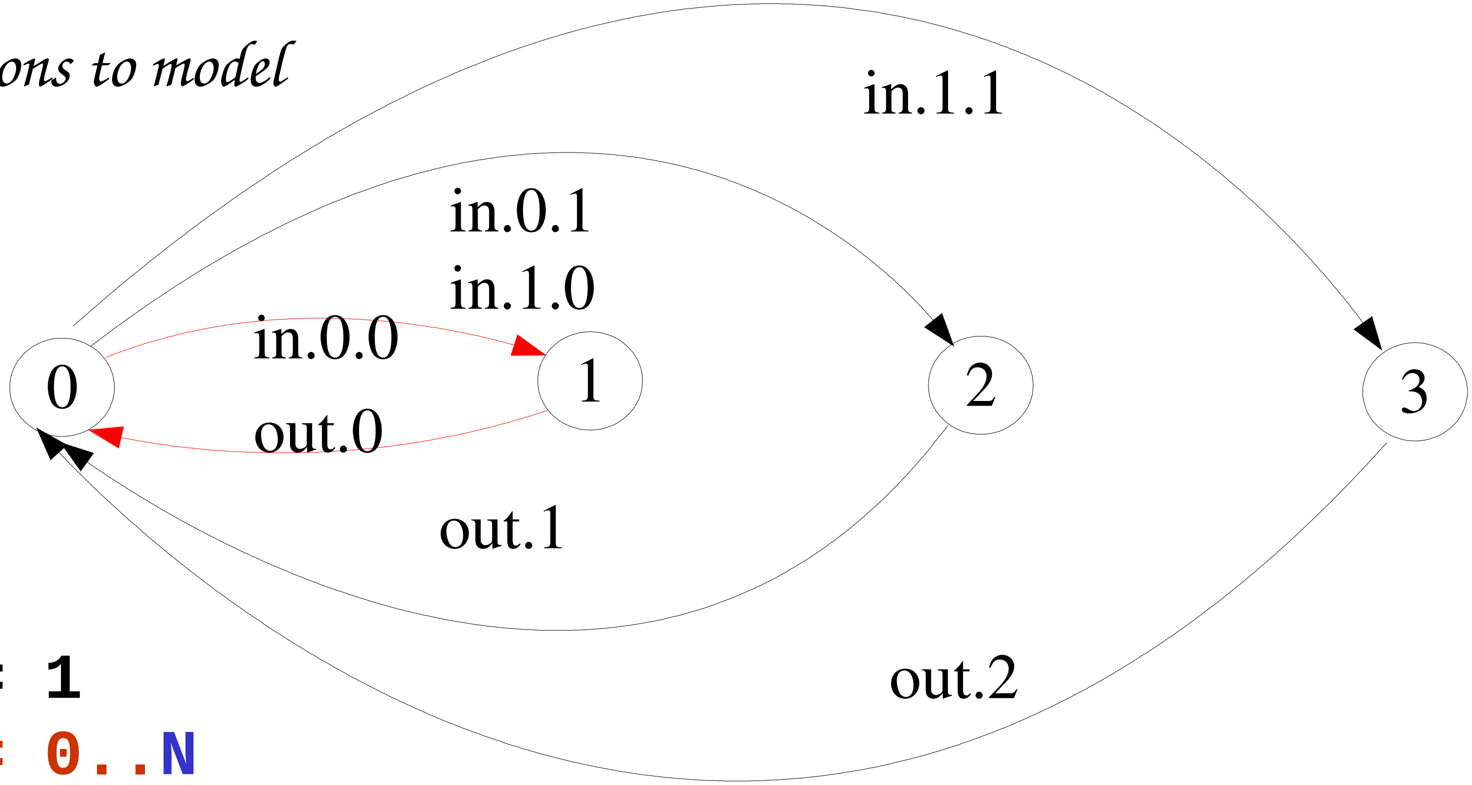
index expressions to model calculation:



```
const N = 1

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

FSP – Constant and Range Declaration

index expressions to model calculation:



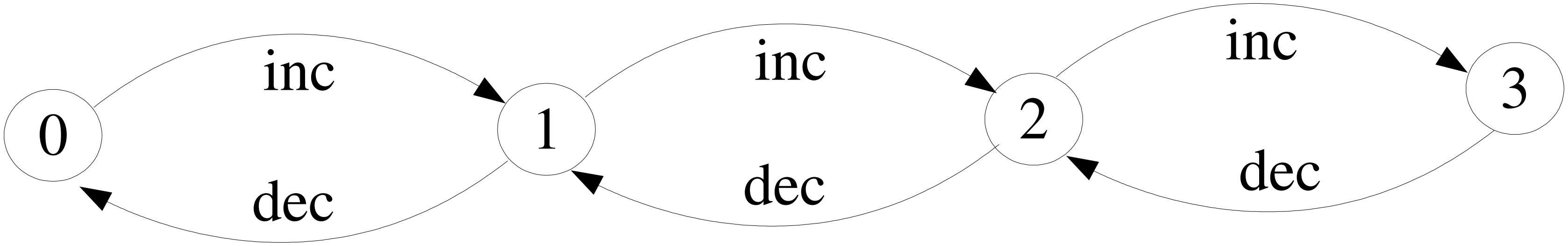
```
const N = 1
range T = 0..N
range R = 0..2*N

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

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.*

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

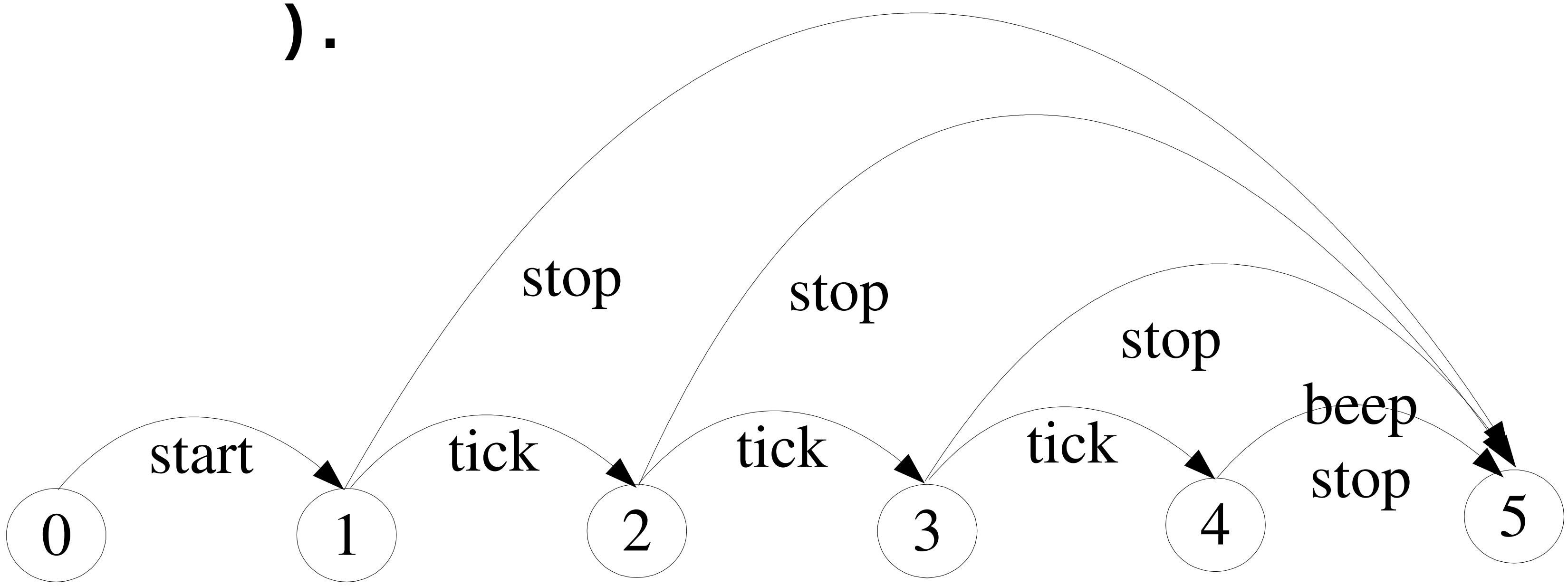
LTS?



FSP – Guarded Actions

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
        ).
```



FSP – Guarded Actions

What is the following FSP process equivalent to?

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

Answer:

FSP – Guarded Actions

What is the following FSP process equivalent to?

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

Answer:

STOP

FSP – Process Alphabets

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

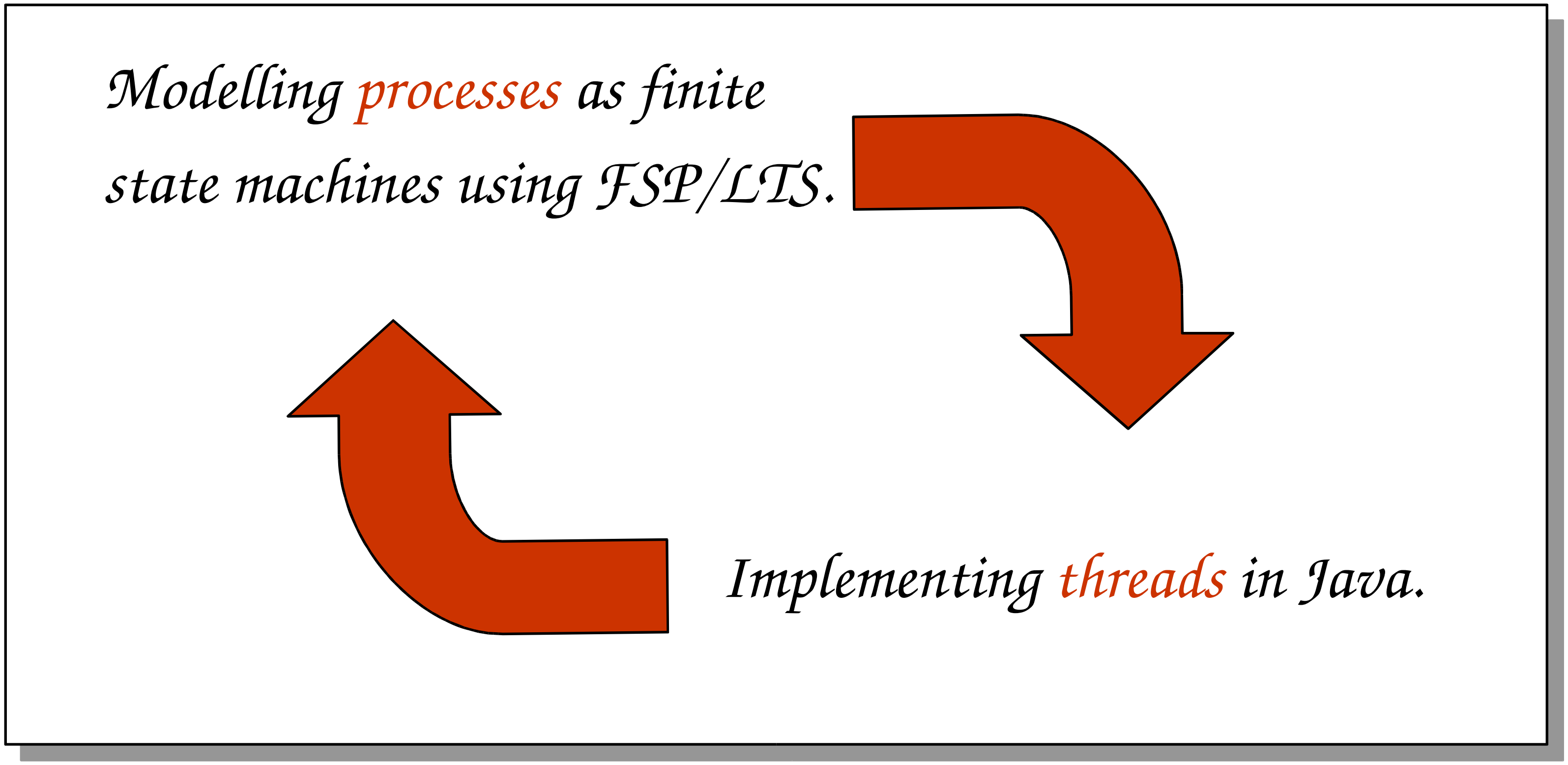
Alphabet extension can be used to extend the **implicit** *alphabet of a process:*

```
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)

Implementing Processes



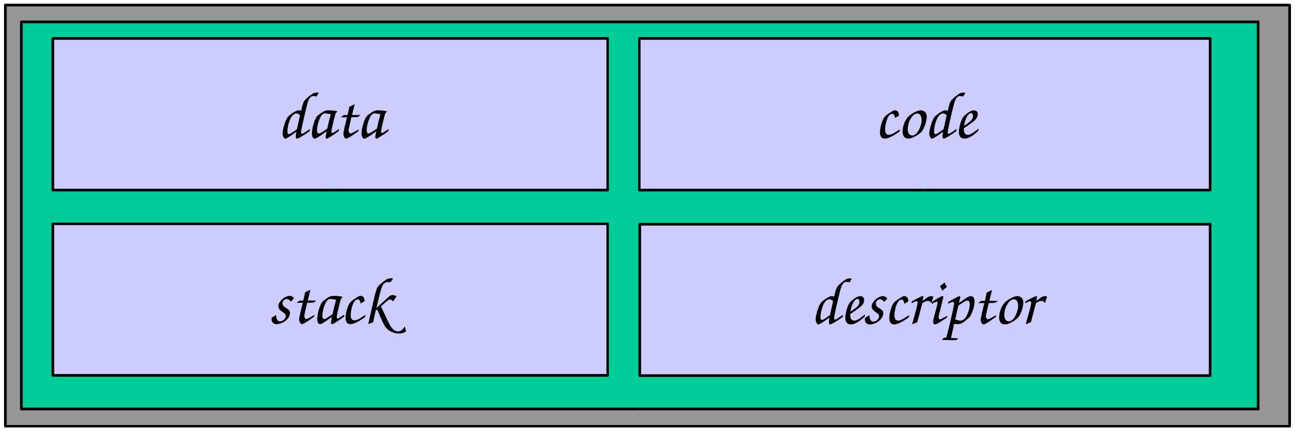
Modelling processes as finite state machines using FSP/LTS.

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.*

Process

- 1 Process:



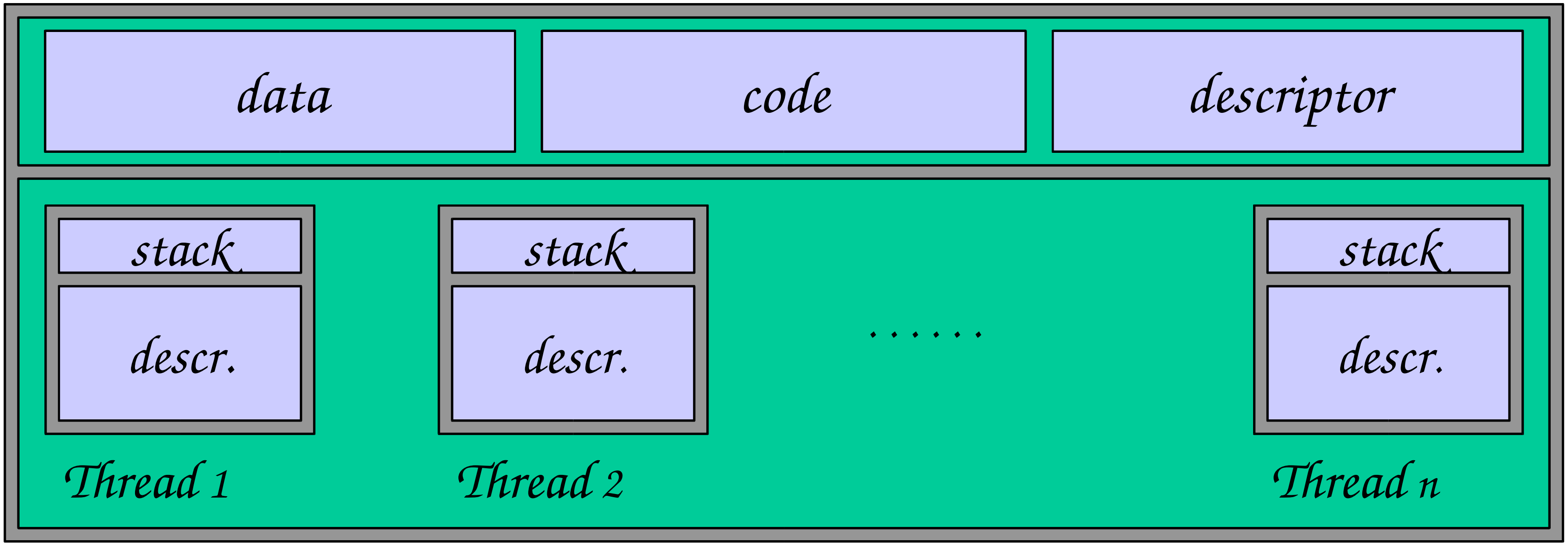
data *code*

stack *descriptor*

- 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

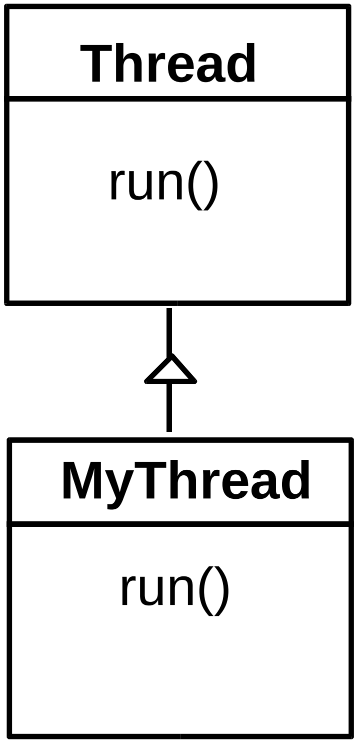
A multi-threaded process



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. Threads may be created and deleted dynamically.



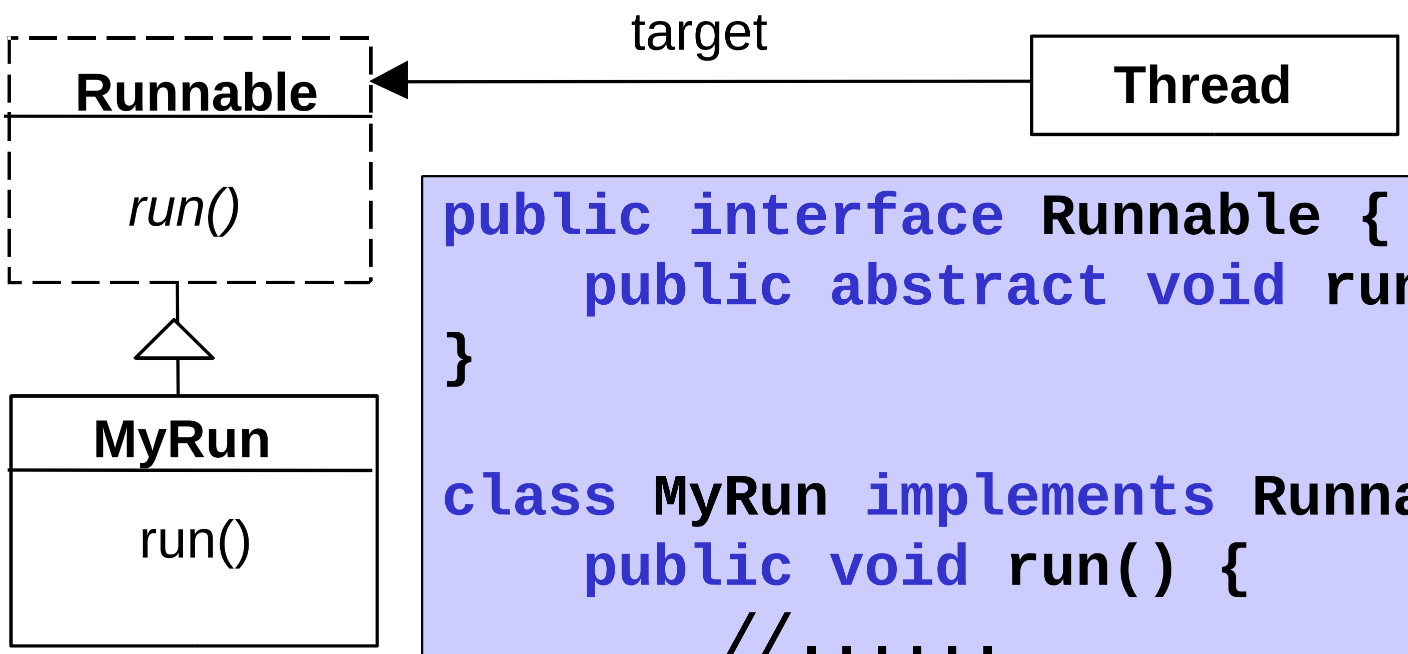
The Thread class executes instructions from its method run(). The actual code executed depends on the implementation provided for run() in a derived class.

```
class MyThread extends Thread {
    public void run() {
        //......
    }
}
```

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

Cont.

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.*

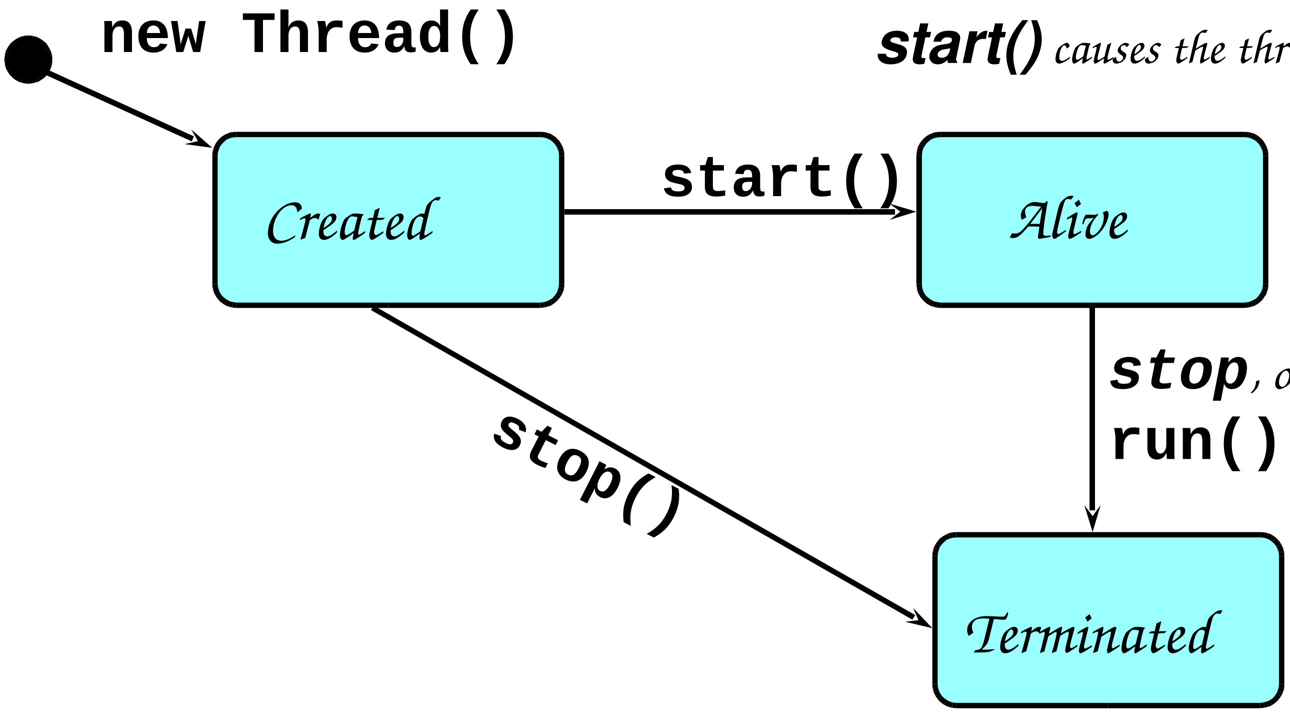


```
public interface Runnable {
    public abstract void run();
}

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

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

Thread Life-cycle in Java

An overview of the life-cycle of a thread as state transitions:

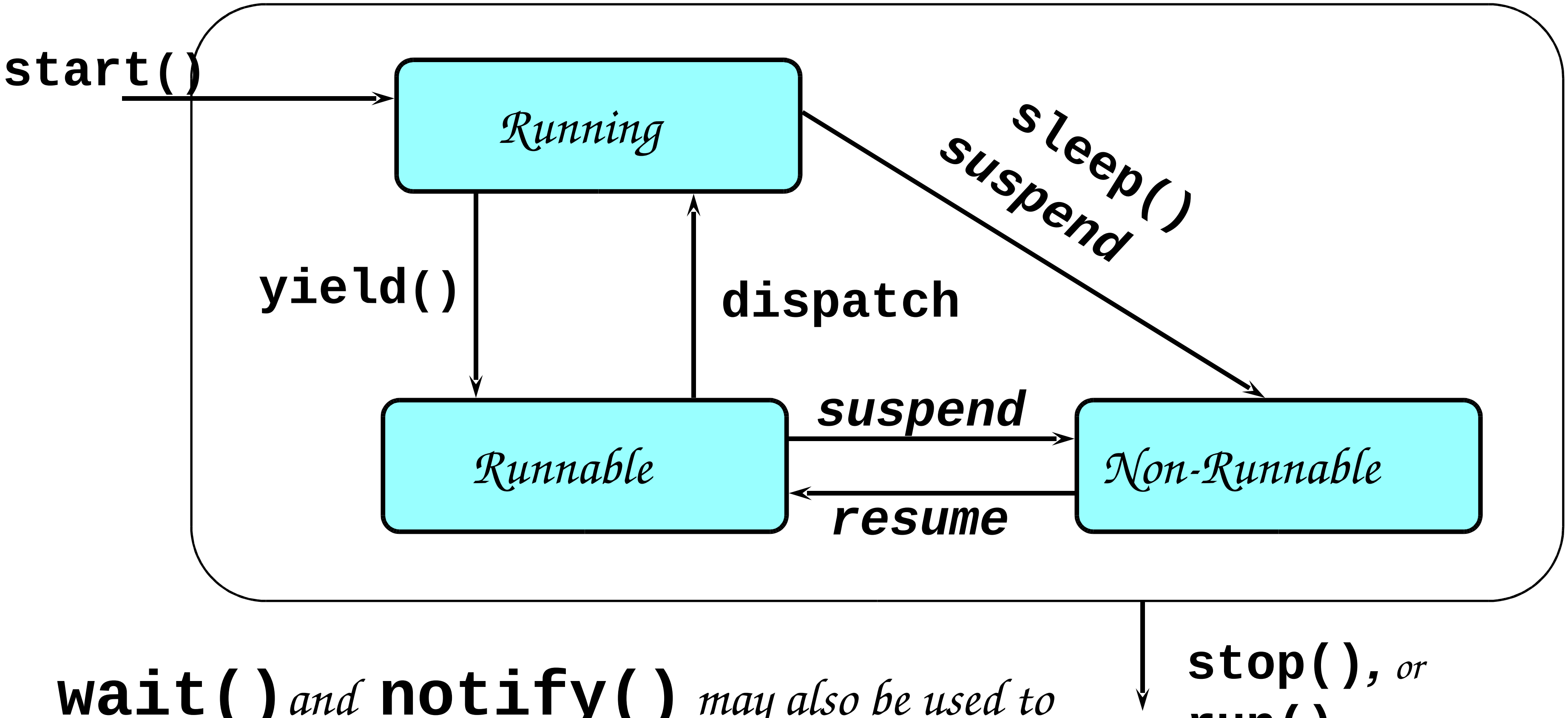


start() *causes the thread to call its run() method.*

The predicate **`isAlive()`** *can be used to test if a thread has been started but not terminated. Once terminated, it cannot be restarted (see mortals).*

Cont. *Alive* States

Once started, an **alive** *thread has a number of sub-states :*

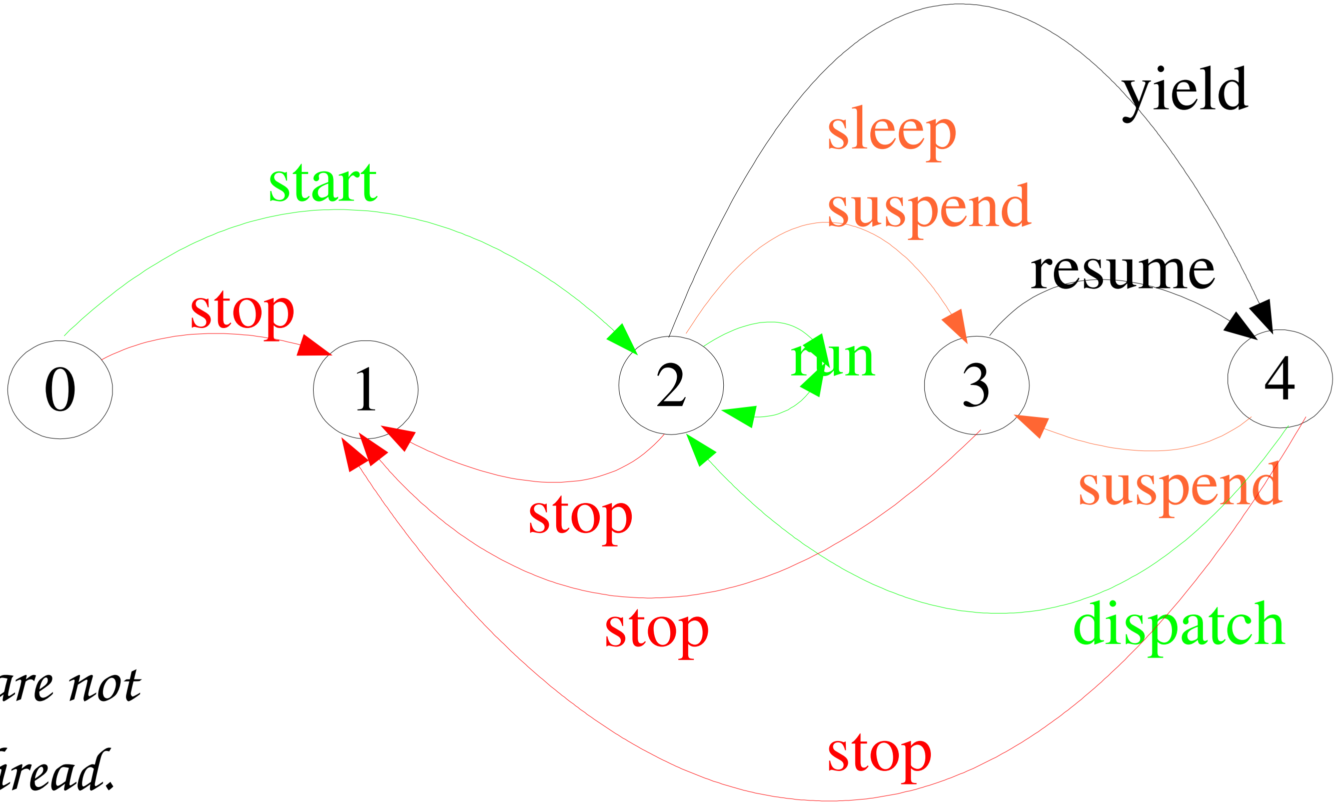


wait() *and* **notify()** *may also be used to change between Runnable and Non-Runnable*

Jave Thread Life-cycle: FSP

```
THREAD       = CREATED,
CREATED      = (start            ->RUNNING
               |stop             ->TERMINATED),
RUNNING      = ({suspend,sleep}->NON_RUNNABLE

               |yield            ->RUNNABLE
               |{stop,end}       ->TERMINATED

               |run              ->RUNNING),
RUNNABLE     = (suspend          ->NON_RUNNABLE
               |dispatch         ->RUNNING
               |stop             ->TERMINATED),
NON_RUNNABLE = (resume           ->RUNNABLE
               |stop             ->TERMINATED),
TERMINATED   = STOP.
```

Java Thread Life-cycle: FSP



`end, run, dispatch` *are not methods of class Thread.*

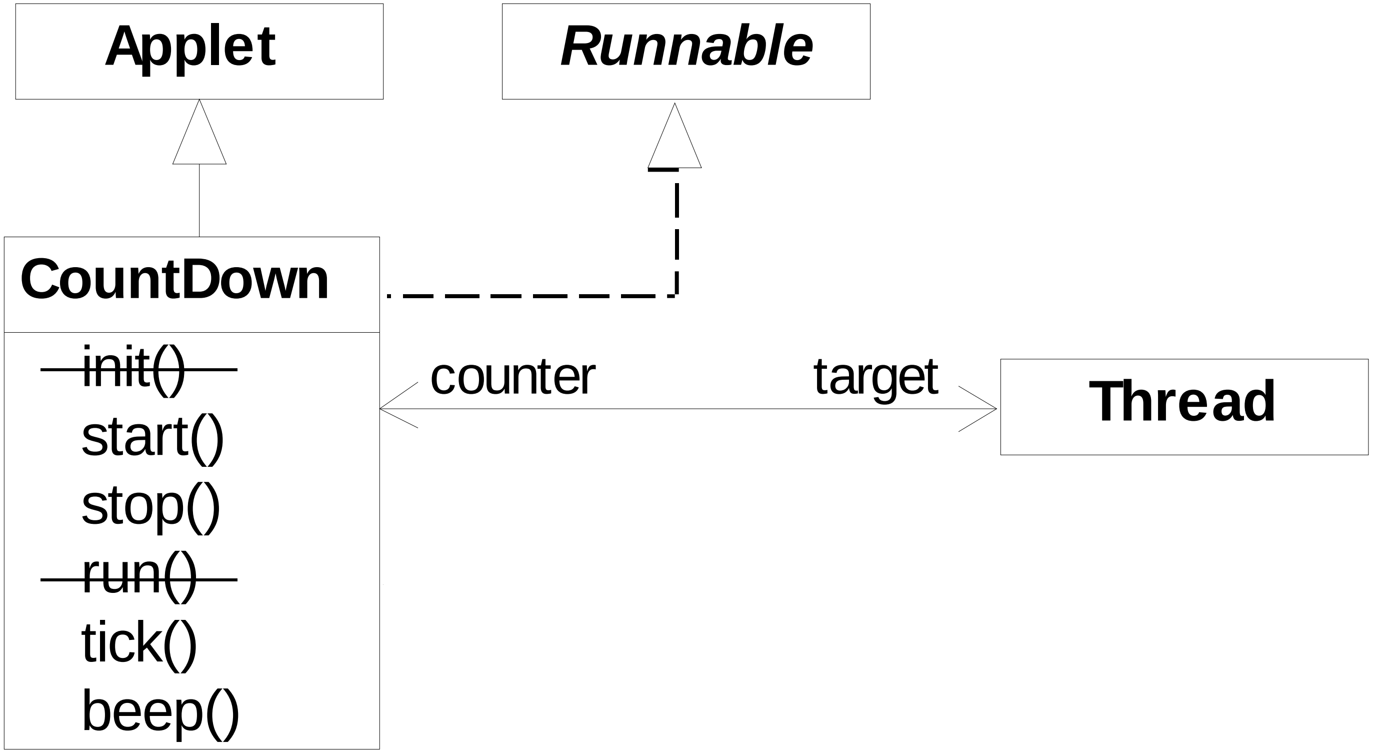
States 0 to 4 correspond to **`CREATED, TERMINATED, RUNNING, NON-RUNNABLE,`** *and* **`RUNNABLE,`** *respectively.*

Countdown Timer - Example

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

Implementation in Java?

Countdown Timer – Class Diagram



Applet

Runnable

CountDown

~~init()~~
start()
stop()
~~run()~~
tick()
beep()

counter

target

Thread

The class **`CountDown`** *derives from* **`Applet`** *and contains the implementation of the* **`run()`** *method which is required by* **`Thread`**.

Countdown Timer - Class

```
public class CountDown extends Applet
                       implements Runnable {
  Thread counter;
  int i;
  final static int N = 10;

  void init()  { ... }
  void run()   { ... }
  void start() { ... }
  void stop()  { ... }
  void tick()  { ... }
  void beep()  { ... }
}
```

Class/Model of 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 (counter == null) return;
      if (i>0)  { tick(); --i; }
      if (i==0) { beep(); return;}
    }
  }
```

start -> CD[N]

stop -> STOP

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

STOP *when* run() returns

Summary

Concepts: Process – unit of concurrency, execution of a program

Models: LTS to model processes as state machines – sequences of atomic actions

FSP to specify processes using prefix "->", choice "| " and recursion

Practice: Java threads to implement processes

Thread life-cycle (created, running, runnable, non-runnable, terminated)