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INF

FAKULTÄT FÜR
INFORMATIK

Introduction to Simulation

Stochastic Petri Nets

Motivation

When performing simulation studies...

- Real problems are very complex

Simulation program = conceptual model is a bad idea!

- Program code is not intuitive or flexible enough

We need a clear, flexible conceptual modelling tool

- To obtain a basic understanding of the system
- As a basis for discussions

Stochastic Petri Nets (SPNs) are a good example

Uses of Stochastic Petri Nets

Stochastic Petri Nets are used as conceptual models in...

- Traffic and Logistics
- Reliability and Safety
- Manufacturing and Production
- Computers and Computer Networks

Advantages of SPNs

Stochastic Petri nets...

- are a graphical modelling tool
- are easy to understand
- are flexible and powerful
- can be easily extended
- can be automatically converted into a simulation model

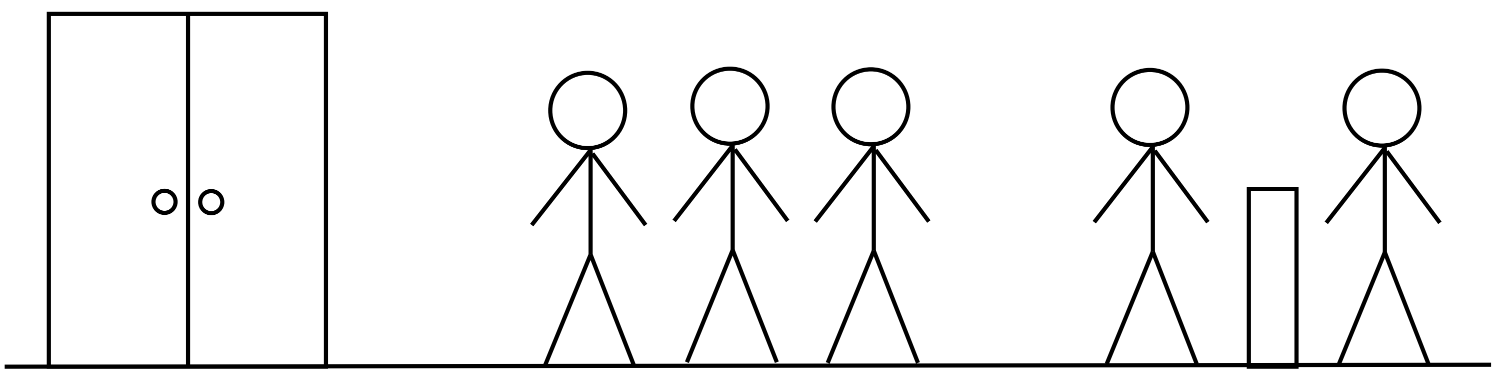
Components of SPNs

Stochastic Petri nets consist of:

- Tokens
- Places
- Transitions
- Arcs (Input, Output and Inhibitor)
- Guard functions
- (...)

Example

A simple queueing system in a bank:



Example

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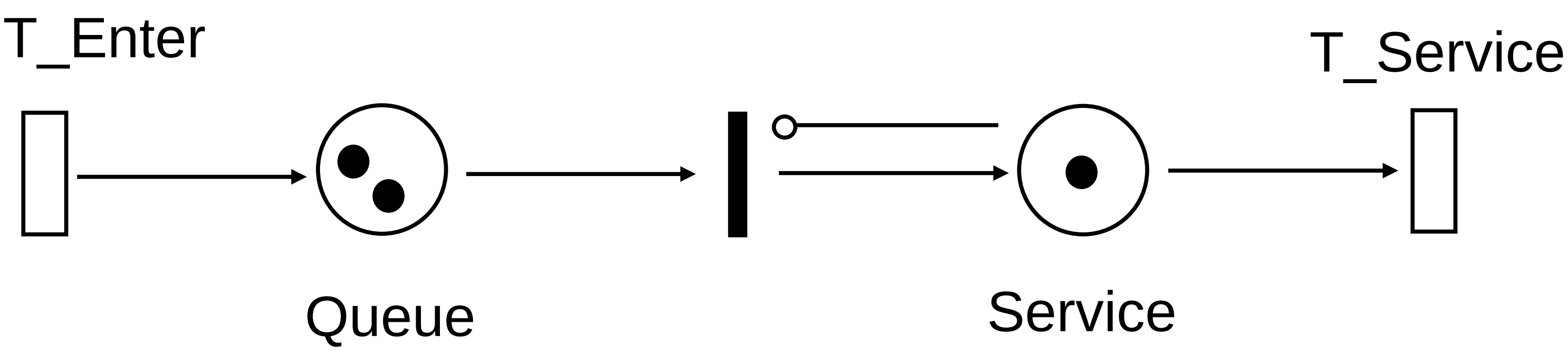
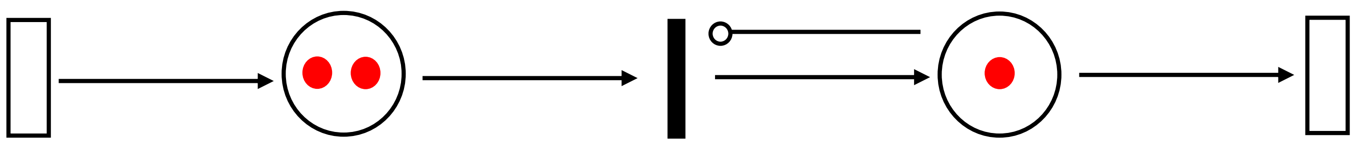


Tokens

Tokens...

- represent objects (entities) or state markers
- are drawn as dots
- are located in places
- are created and destroyed by the firing of transitions



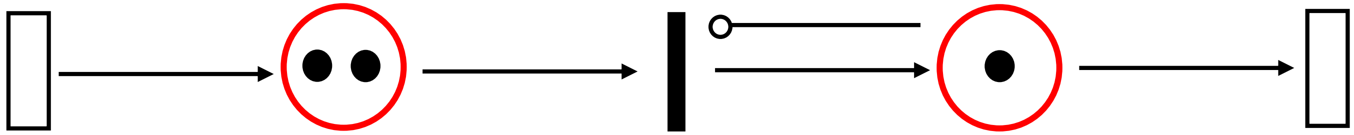
The distribution of tokens in the places is called the marking

- The marking in the above SPN is (2, 1)

Places

Places...

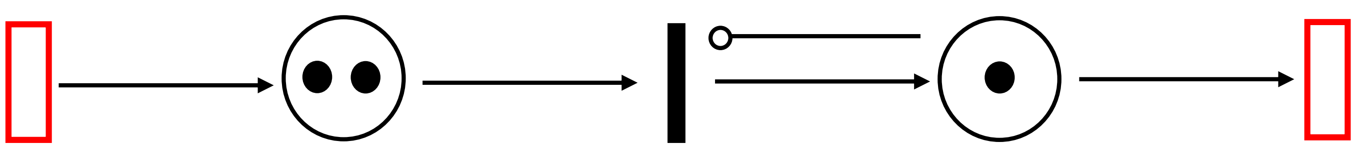
- represent locations or states
- are drawn as circles
- are used to store tokens



Timed Transitions

Timed transitions...

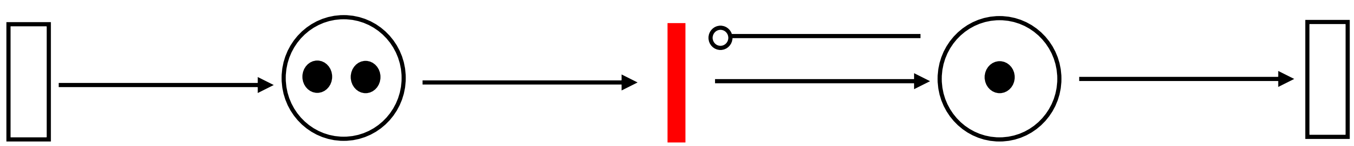
- represent activities and the events which end them
- are drawn as open rectangles
- are used to create and destroy tokens
- have an associated (usually random) firing time



Immediate Transitions

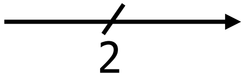
Immediate transitions...

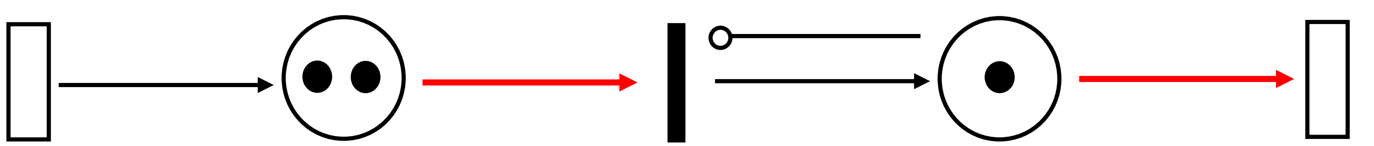
- represent events (without activities)
- are drawn as bars
- are also used to create and destroy tokens
- fire immediately they become enabled
- can have an associated firing probability



Input Arcs

Input arcs...

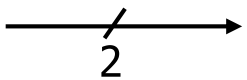
- join places to transitions
- are drawn as arrows
- determine enabling of transitions
- determine # tokens destroyed by firing
- can have a multiplicity 

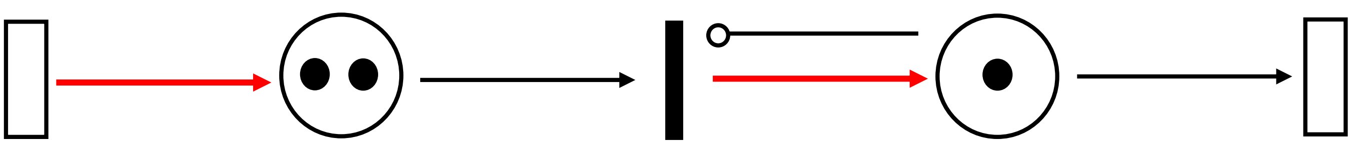


Output Arcs

Output arcs...

- join transitions to places
- are drawn as arrows
- determine # tokens created by firing
- can have a multiplicity

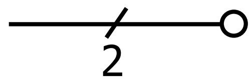


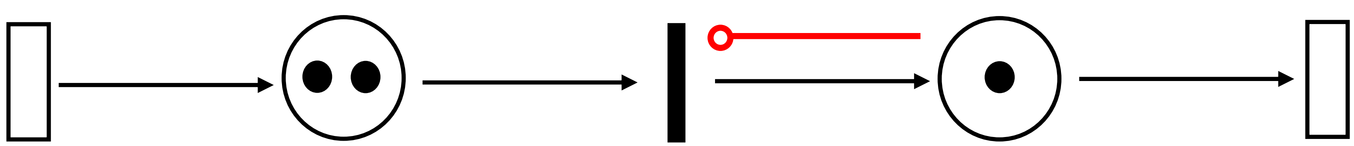


Inhibitor Arcs

Inhibitor arcs...

- join places to transitions
- are drawn as arrows with circular heads
- disable transitions when enough tokens are in place
- can have a multiplicity



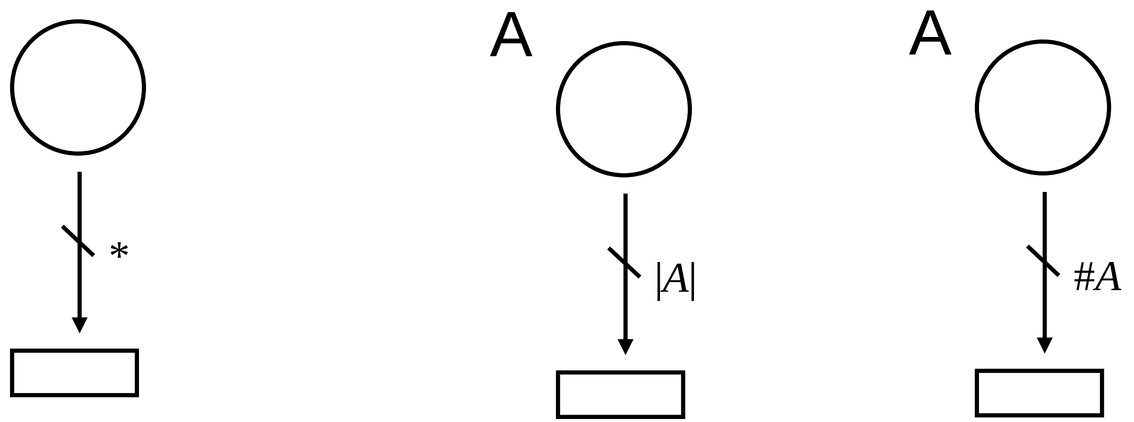


Variable Multiplicity Arcs

Arcs may also have variable multiplicities

- * or |A| or #A means the number of tokens in place A

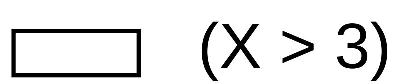
The multiplicity can thus also be marking-dependent



Guard Functions

Guard functions...

- are assigned to transitions
- map markings to Boolean values
- disable transitions when their value = FALSE
- allow general conditions for disabling



Firing Rules

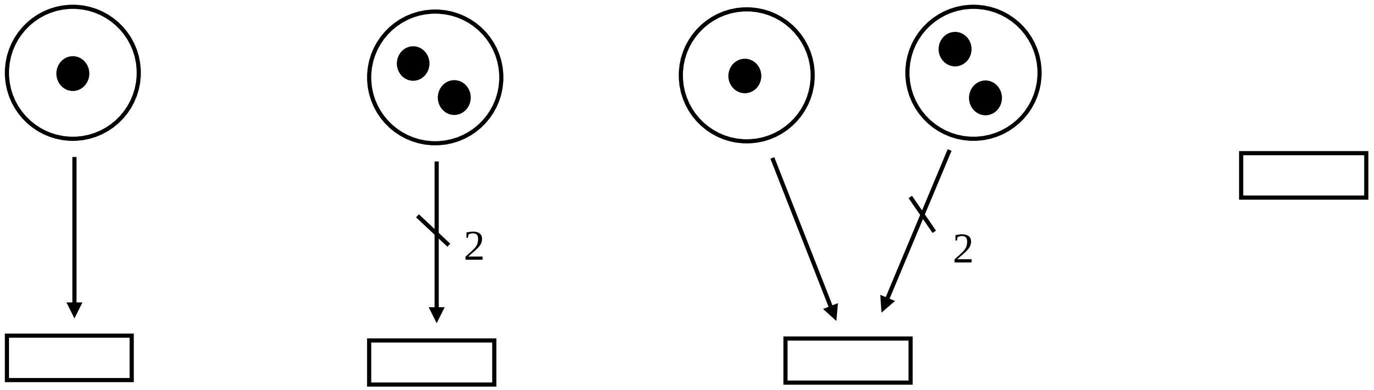
A transition can *fire* if it is *enabled*, i.e. ...

- The number of tokens in every input place >= multiplicity of the corresponding input arc
- there are no inhibitor arcs currently active
- no guard functions return FALSE

Otherwise, the transition is *disabled*, and cannot fire

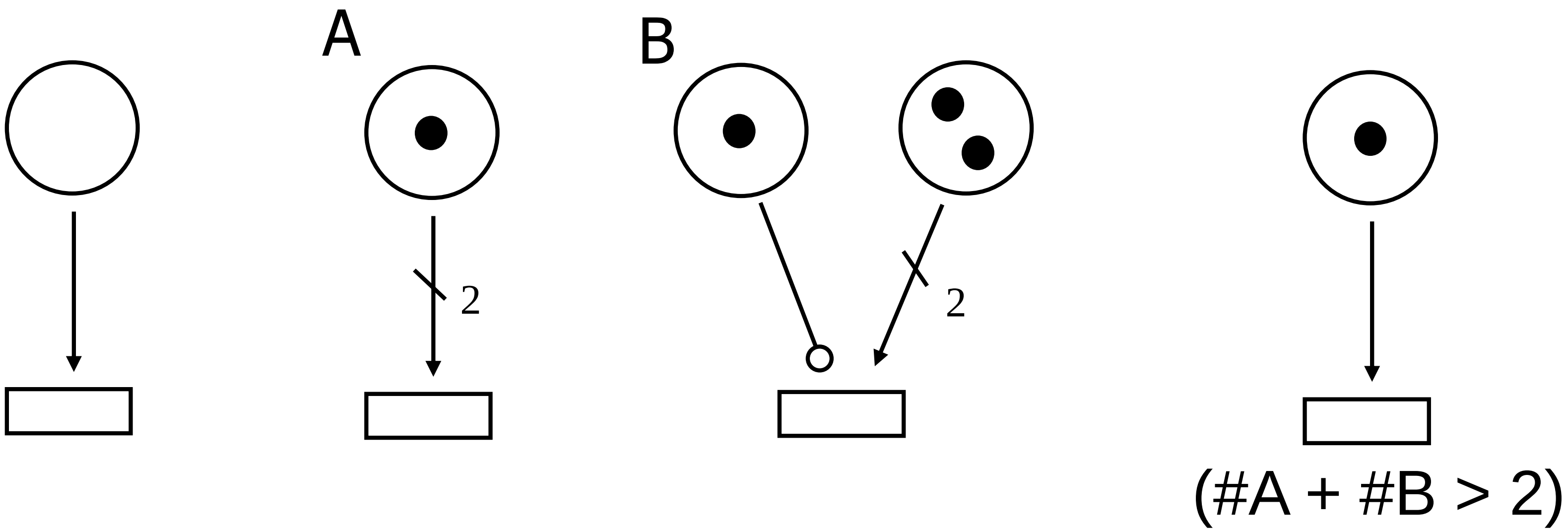
Enabling Examples

Some enabled transitions:



Disabling Examples

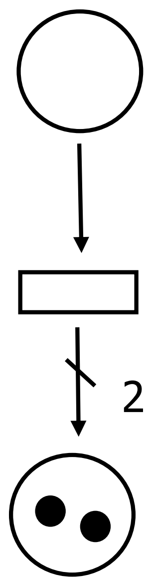
Some disabled transitions:

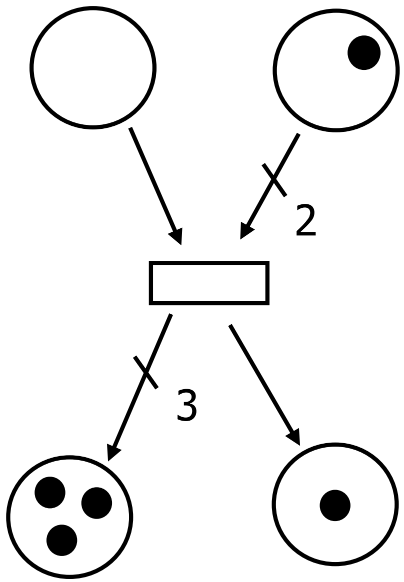


Effects of Firing

Effects of firing:

- The tokens that enable the transition are destroyed
- Tokens are created in output places according to the multiplicity of the output arcs

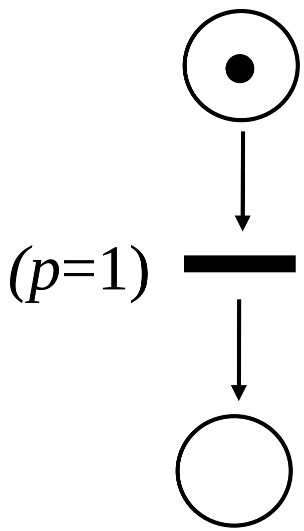


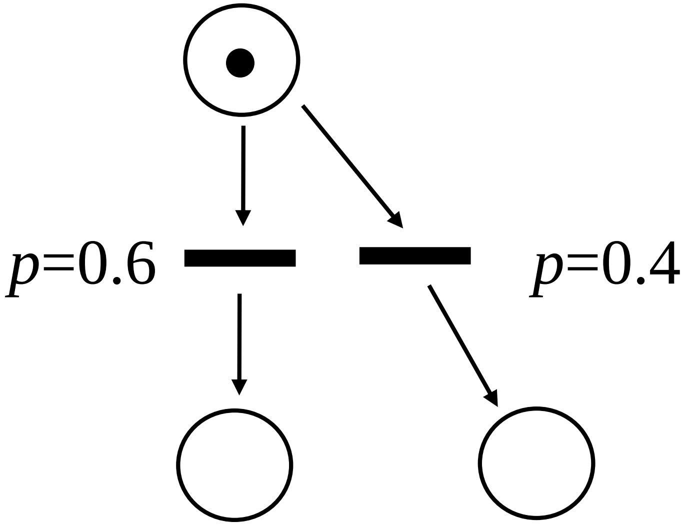


Firing Examples

Firing timing for an immediate transition:

- It fires as soon as it becomes enabled
- Simultaneously enabled immediate transitions compete, using probabilities

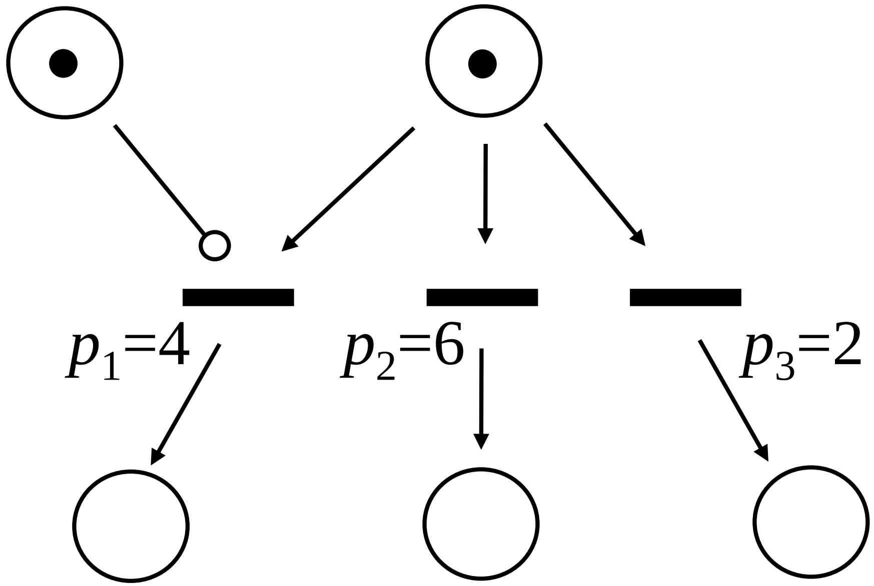




Firing Examples

Firing probabilities for an immediate transition:

- The probabilities are computed relative to all currently enabled transitions



$$p_1^* = 0$$

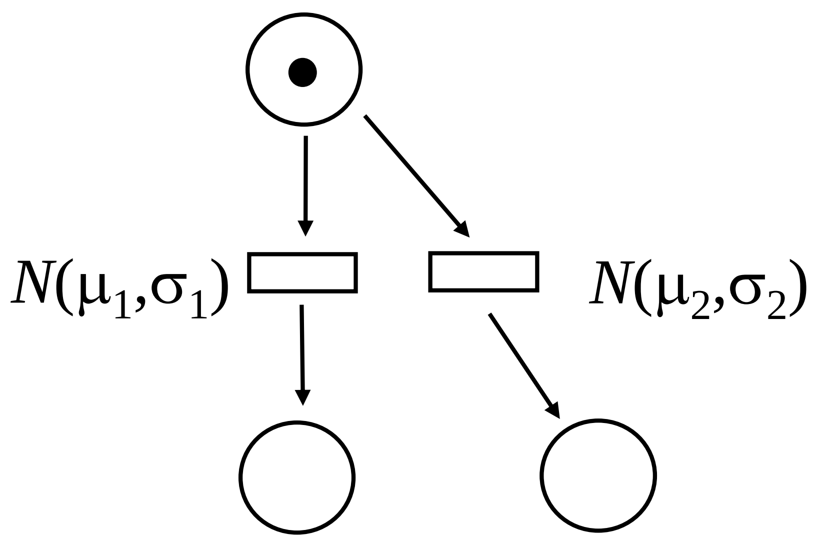
$$p_2^* = \frac{p_2}{p_2 + p_3}$$

$$p_3^* = \frac{p_3}{p_2 + p_3}$$

Firing Examples

Firing timing for a timed transition:

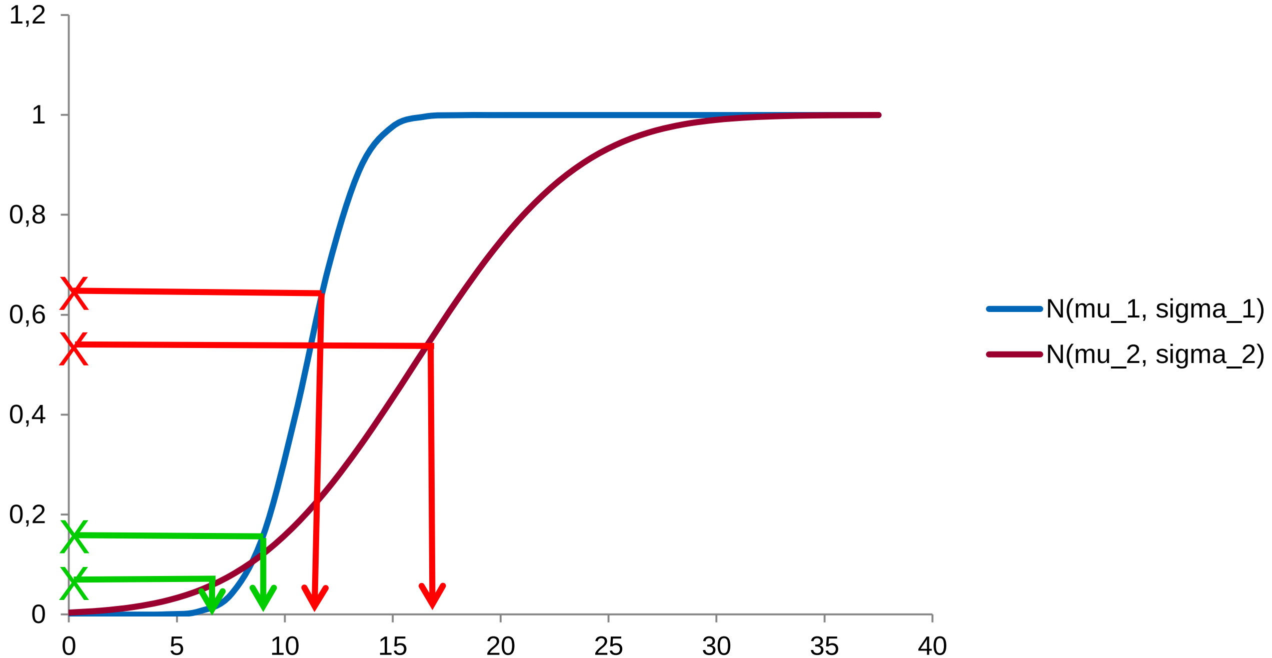
- It fires a certain time after becoming enabled (assuming it is not disabled during that time)
- The delay can be a random variable
- Simultaneously enabled timed transitions "race"



RN in the Simulation

Which transition fires first? (What is the result of the race?)

- That depends on the random numbers that are sampled!



Age Policies

What happens when a timed transition becomes disabled before it fires?

There are two main alternatives:

- *Race Enable*: The elapsed enabling time is "forgotten"
- *Race Age*: The elapsed enabling time is "remembered"

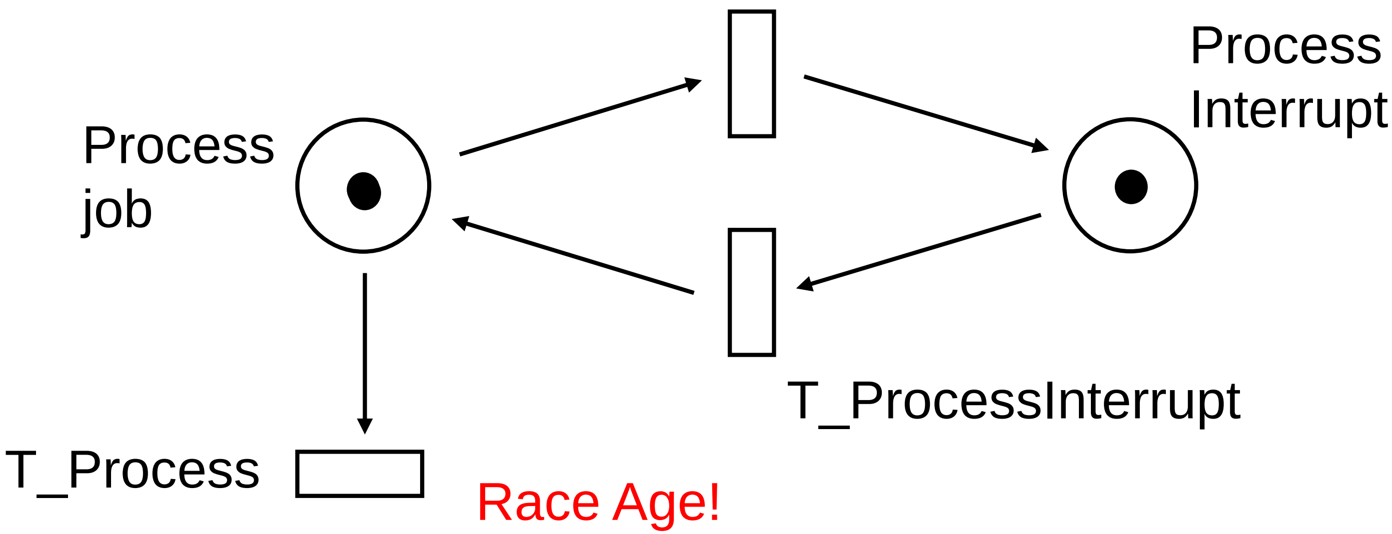
When the transition is re-enabled…

- The Race Enable transition will sample a new firing time
- The Race Age transition will use up its remaining firing time

Race Age

Example for the Race Age memory policy:

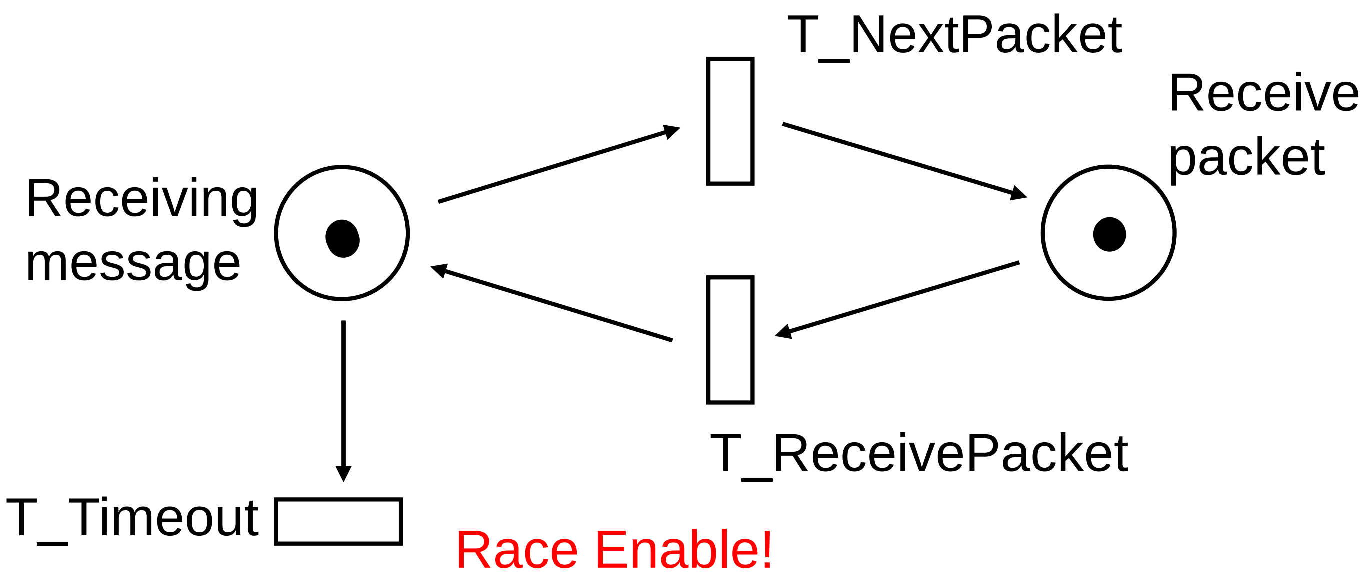
- A CPU processes a user job
- The CPU can be interrupted



Race Enable

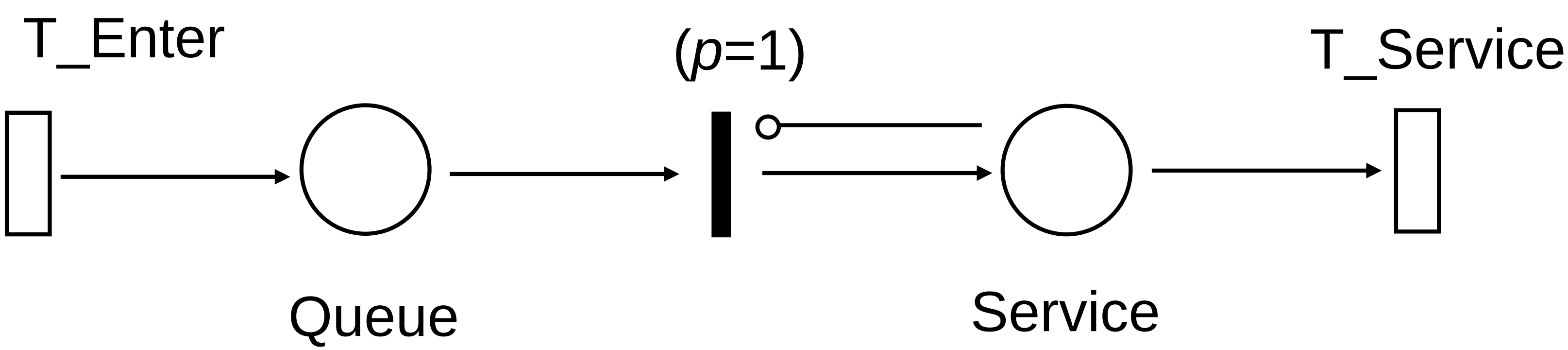
Example for the Race Enable memory policy:

- A networked computer receives message packets
- A timeout occurs if a packet is delayed for too long



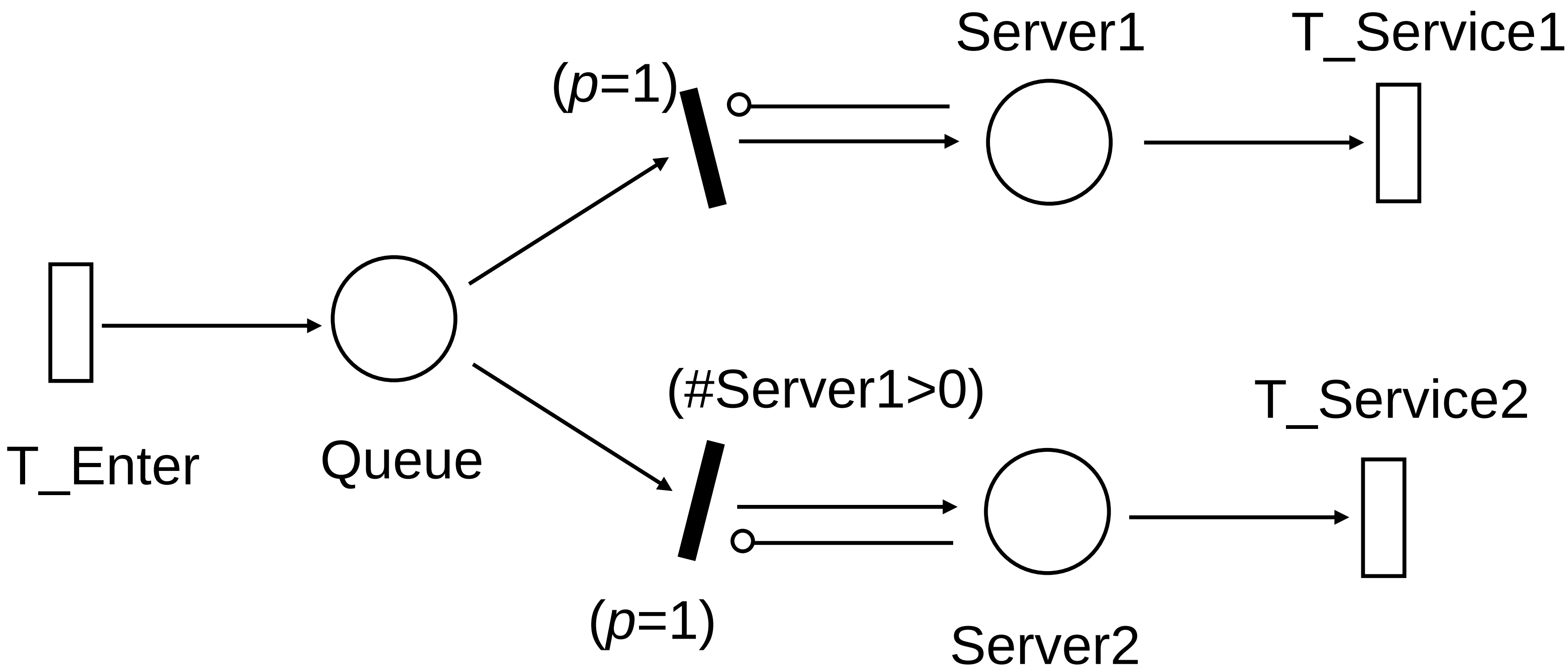
Example: The Bank

A simple queueing system in a bank:



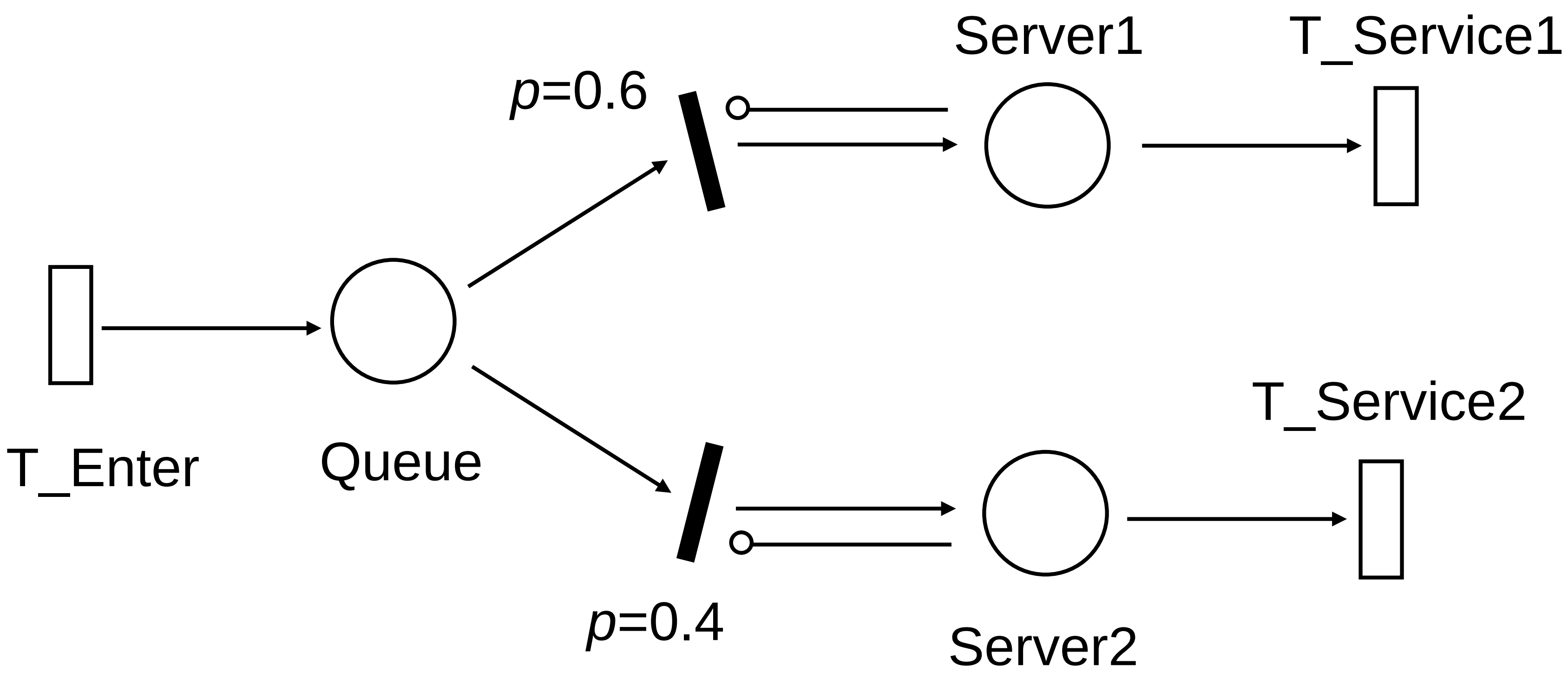
Example: The Bank

Petri net for two servers (Server 1 has priority):



Example: The Bank

Petri net for two servers (probabilistic choice):



Process Characteristics

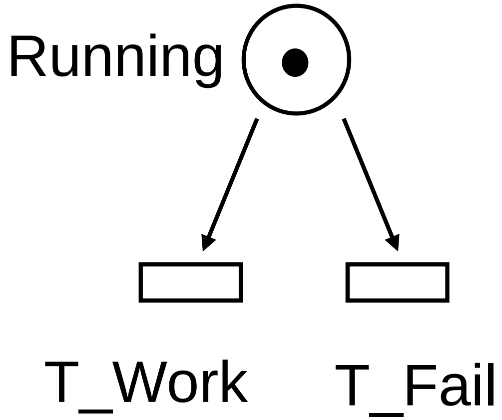
Processes have several characteristic elements:

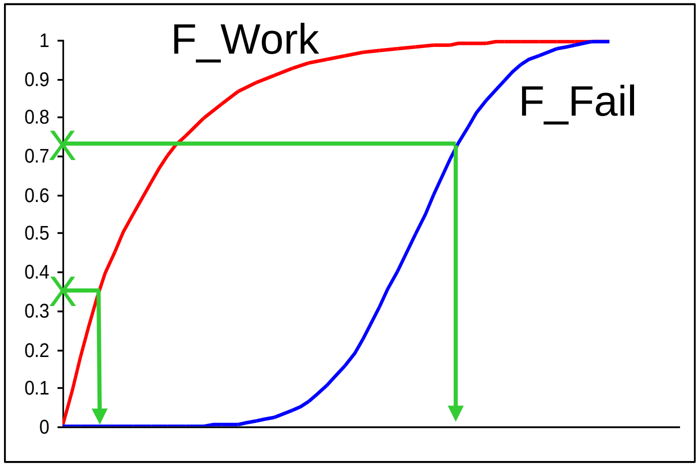
- Competition: A "race" between two or more processes
- Fork: A process splits into subprocesses
- Join (synchronise): Two or more processes unite
- Concurrency: Processes that happen in parallel
- Limited resources: Different processes share a resource
- Probabilistic choice: Choose at random

These elements can all be modelled easily with SPNs

Competition

Modelling of competing processes:



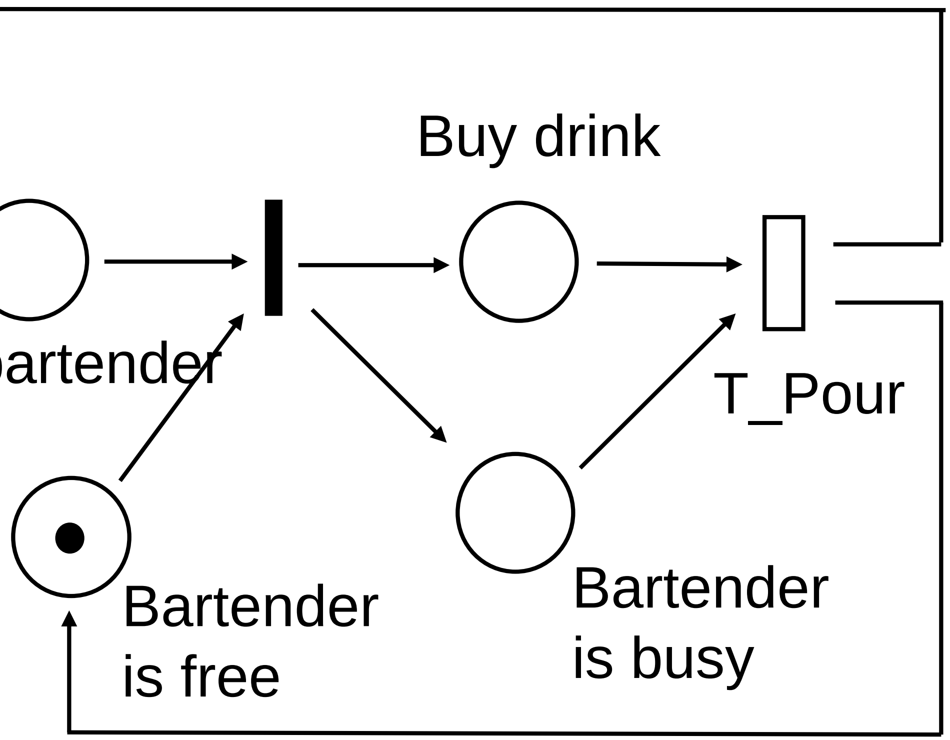


The simulator samples the Work and Fail distributions

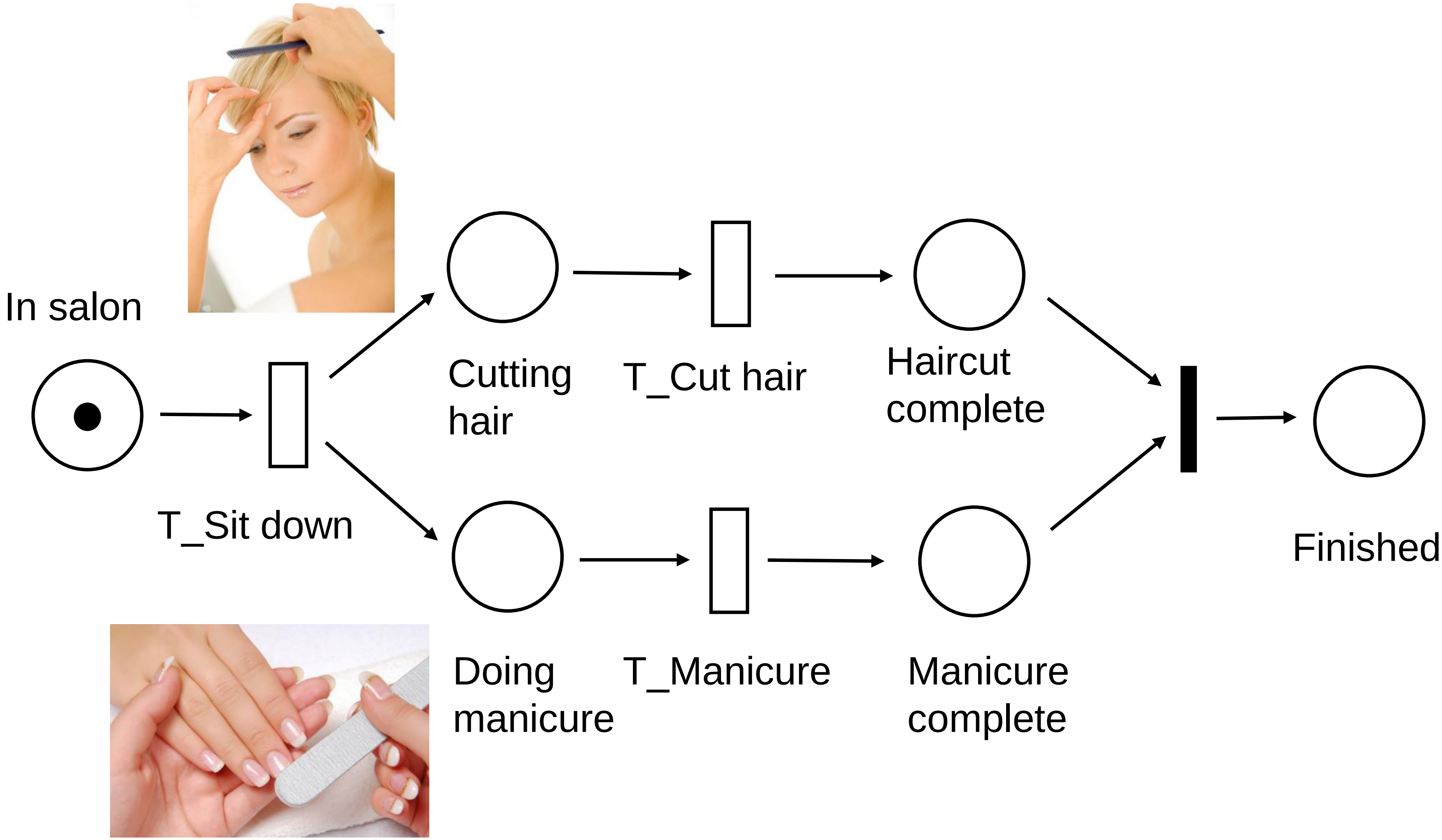
- The faster transition wins

Example: The Bar

Modelling of a limited resource:

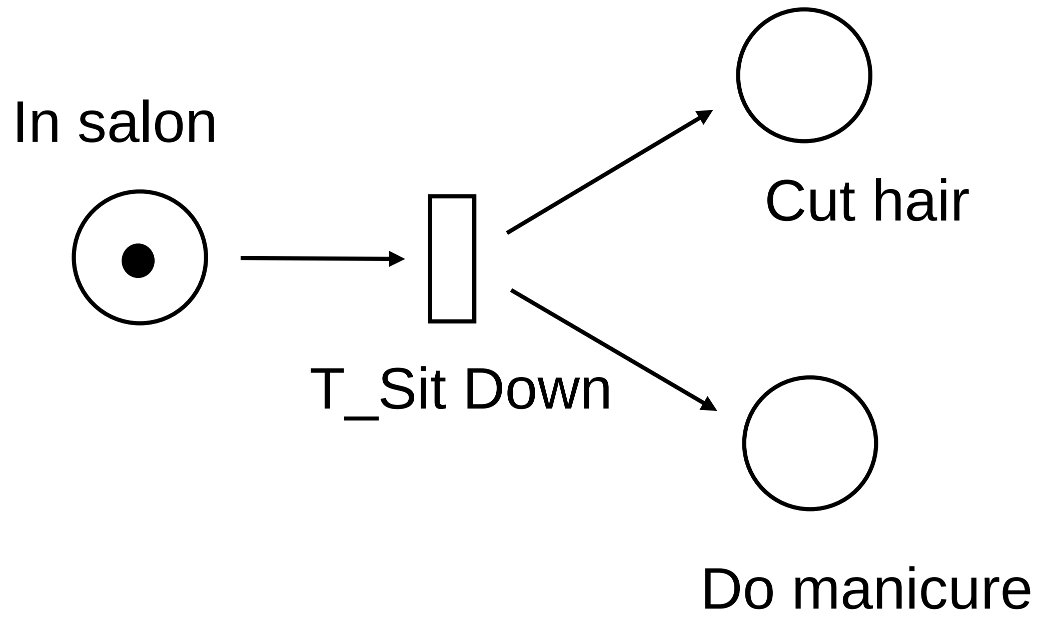


Example: The Beauty Salon



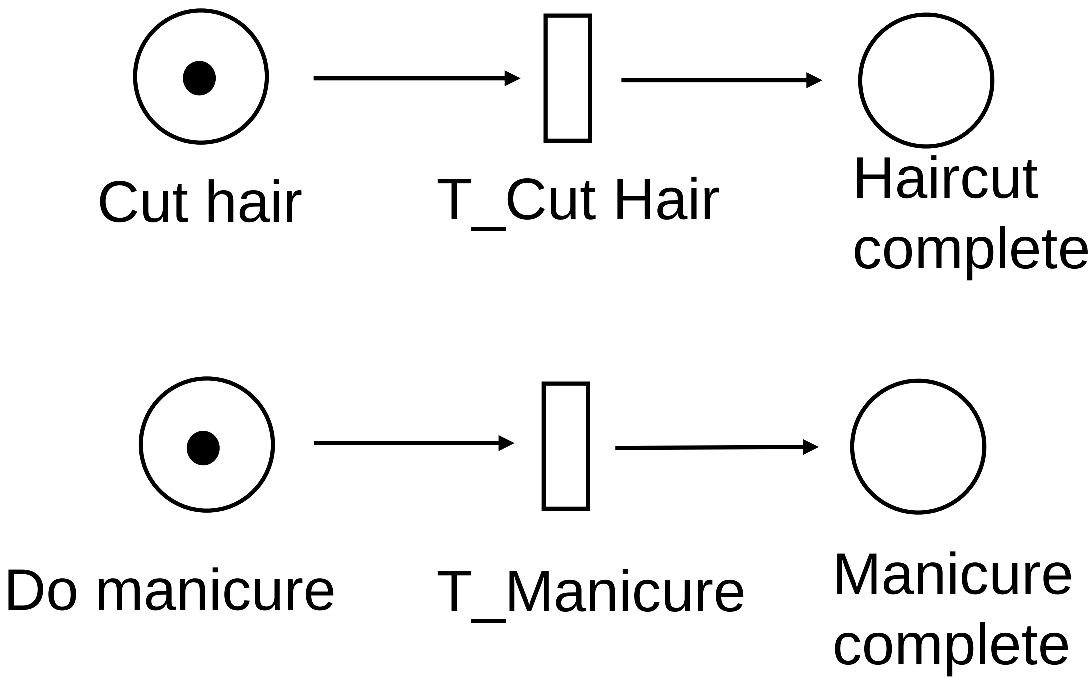
Example: The Beauty Salon

Modelling of a fork process:



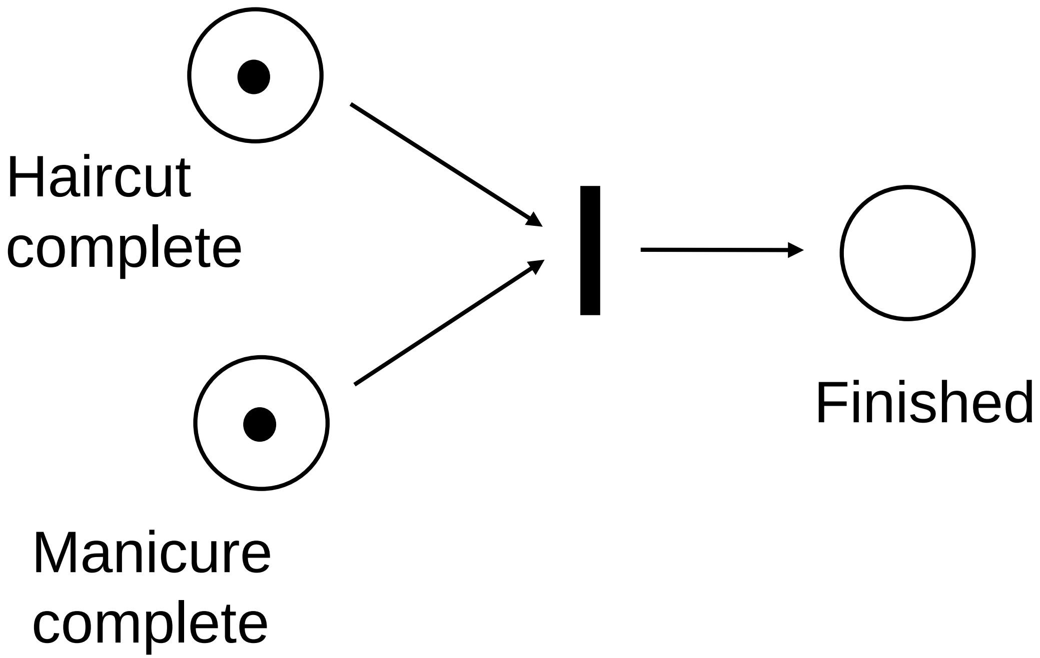
Example: The Beauty Salon

Modelling of concurrent processes:

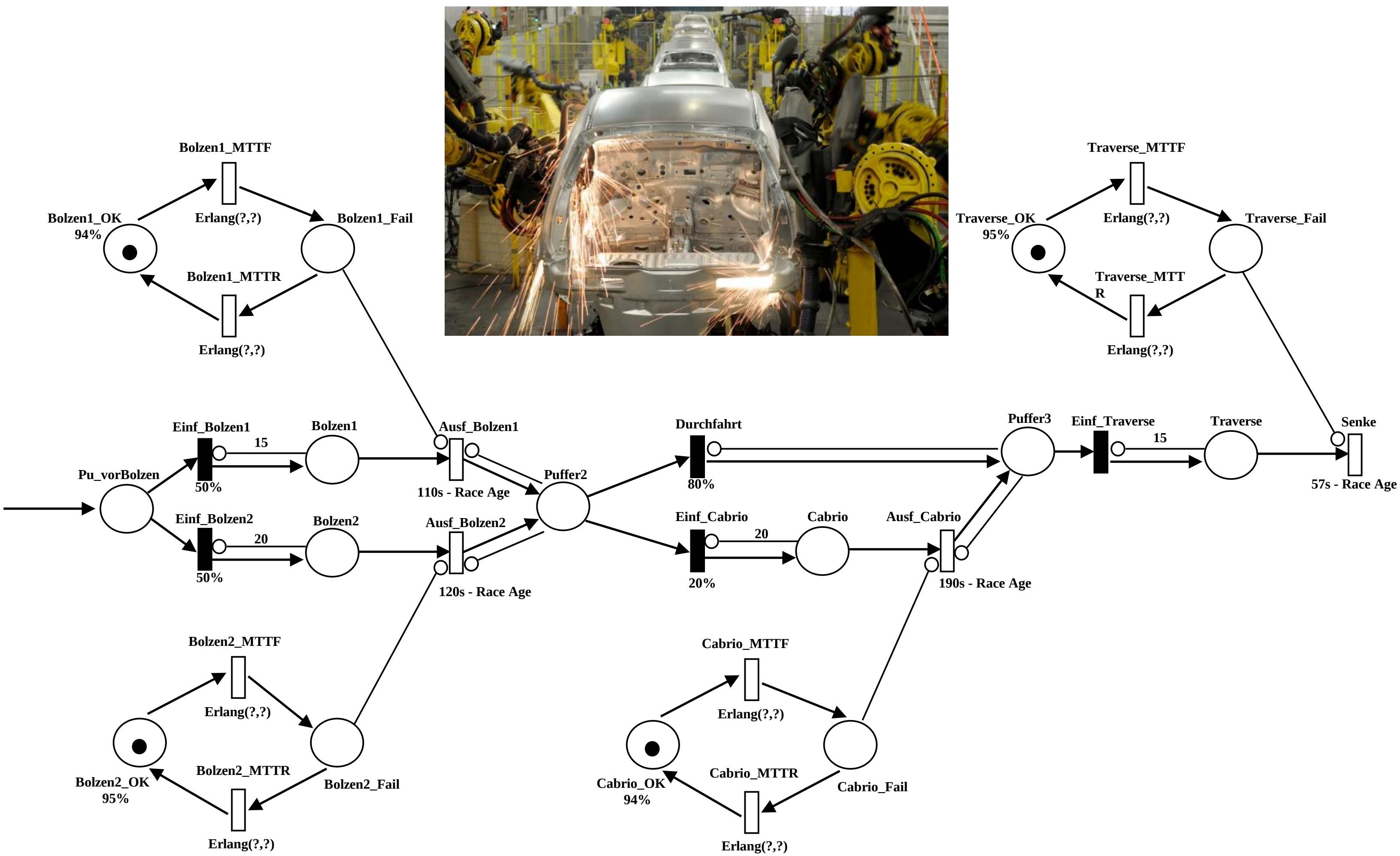


Example: The Beauty Salon

Modelling of a join process (synchronisation):



Modelling an Automobile Factory



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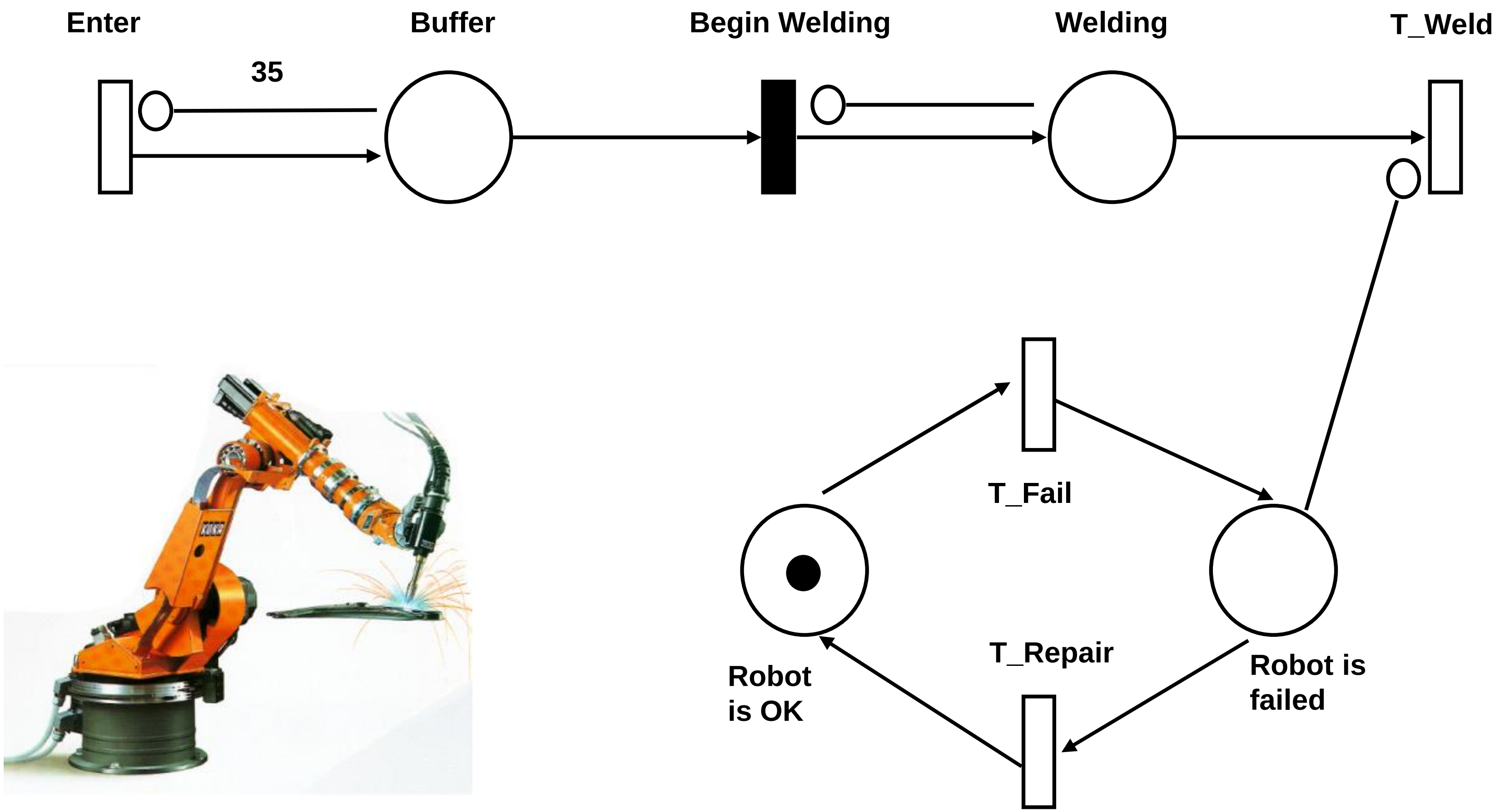
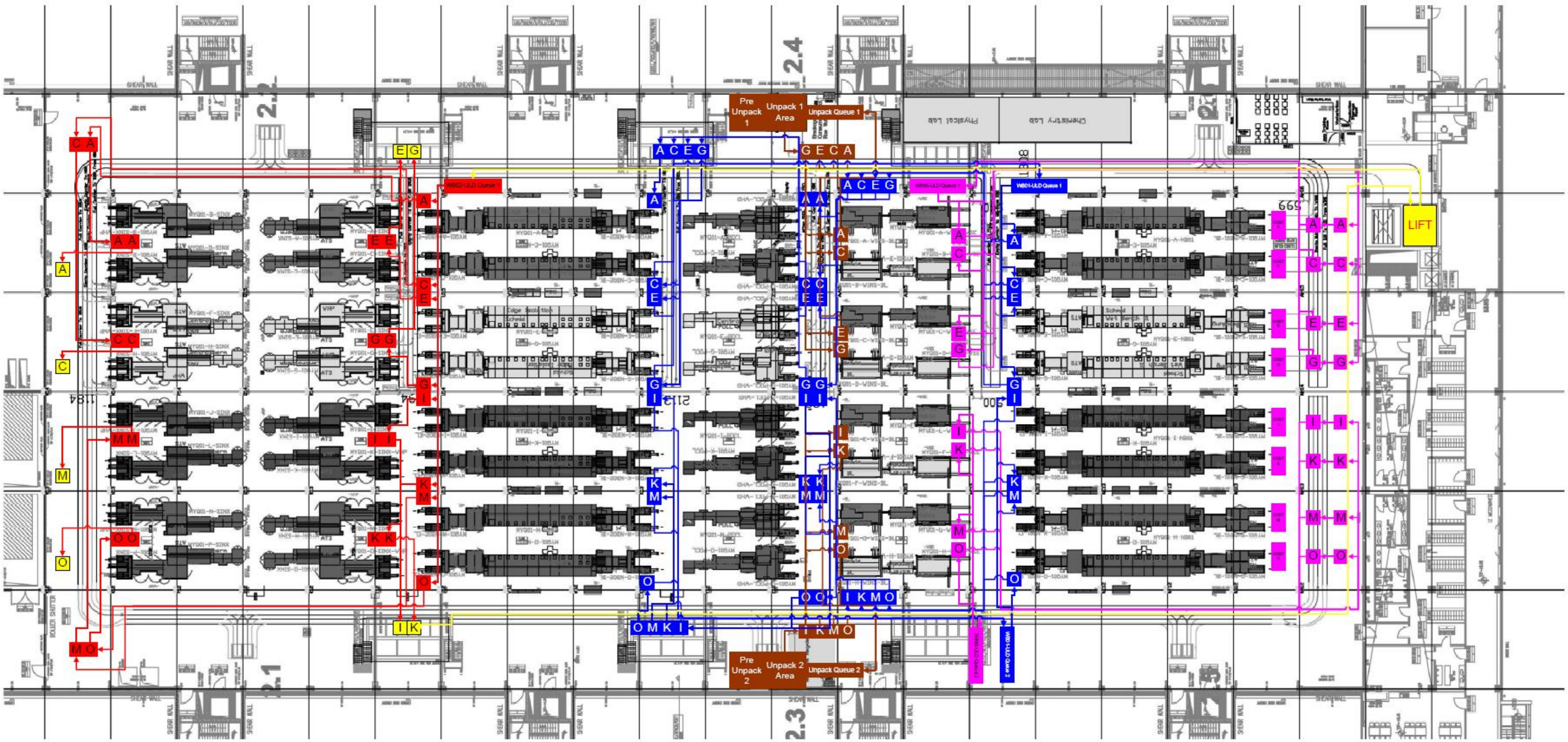


Simulation Project 2010

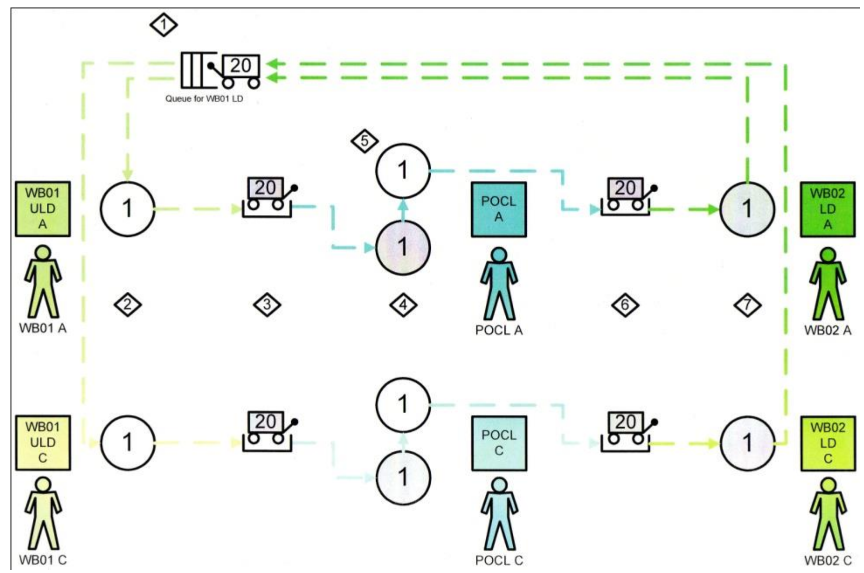
Task of Q-Cells Project:

- Design a wafer transport strategy between machines and trolley capacity for a new Q-Cells facility in Malaysia

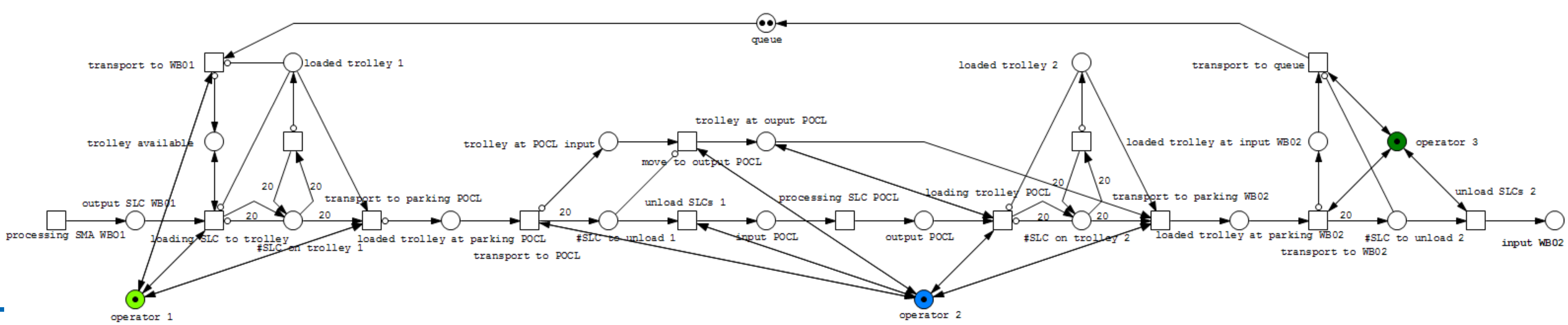


Simulation Project 2010

Schema of trolley based wafer transport in a certain loop involving three machines



Petri net representing that loop's logic



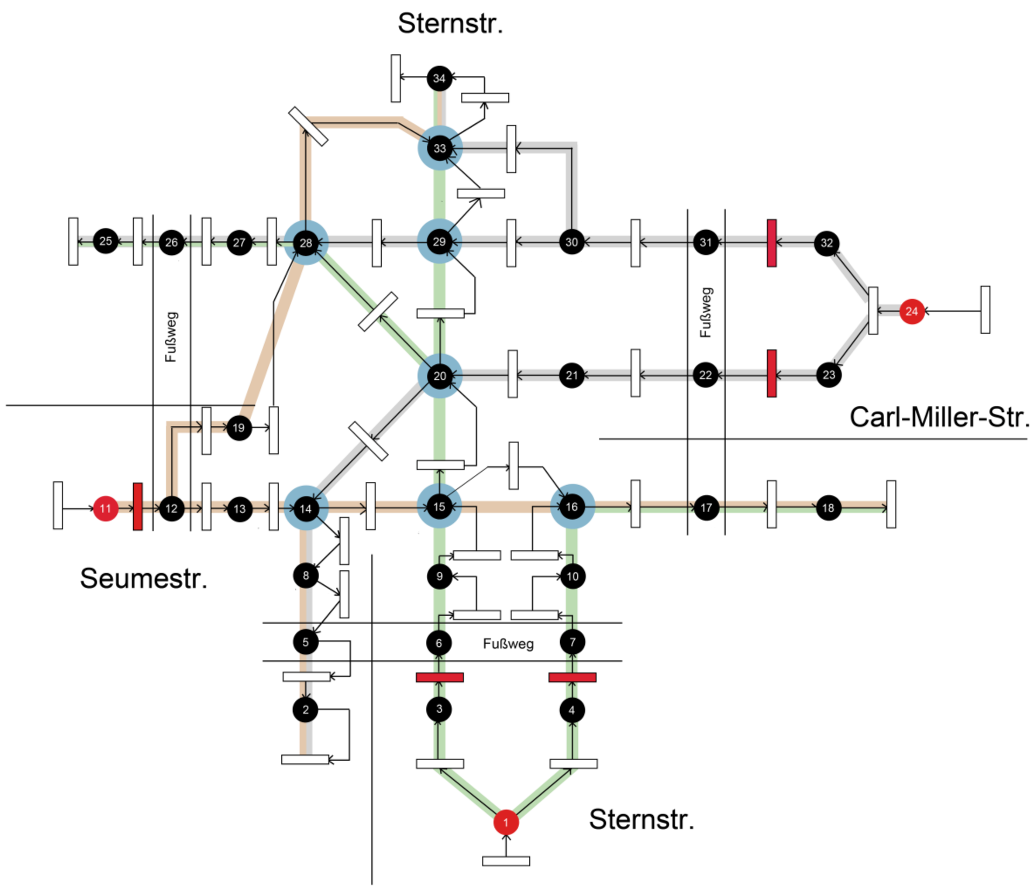
Simulation Project 2012

Crossroads in the center of Magdeburg

- Determine the effect of removing the traffic light considering different traffic conditions

Crossroad in the center of Magdeburg

- Determine the effect of removing the traffic light considering different traffic conditions



The Sims – Almost Normal Family Life

Represent dad's employments with an SPN:

Places can represent :

- Being employed, being unemployed …

Timed transitions represent activities:

- Duration of an employment, duration of unemployment…

Immediate transitions represent probabilities:

- Get a job or stay unemployed …

Star Trek – Enterprise in Danger

Represent the repair and medical treatment cycle with an SPN:

Places can represent treatment stages holding crew members:

- Medical treatment stage 1, waiting for stage 2, repairing…

Timed transitions represent activities:

- Duration of treatment stage 2, time available for repair…

Immediate transitions represent conditions:

- Continue repair, if all crew members have been treated…

Learning Goals

Learning questions:

- Model scenario <…> using a Stochastic Petri Net
- What do Race Age and Race Enable mean?
- What rules govern the firing of a timed transition?
- What rules govern the firing of an immediate transition?
- How are concurrency, fork, join, racing and limited resources represented in a Stochastic Petri Net?