ECE 321
Software Requirements Engineering

LAB 6. Finite State Machines

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Finite State Machines

M = {*Q, I, δ*}, where

– *Q* is a finite set of states

– *I* is a finite set of inputs

– *δ* is a transition function

- defines what is the next state for an input and a state
- $\delta : Q \times I \rightarrow Q$

Example

states Q = {q1, q2, q3}

inputs I = {i1, i2, i3, i4}

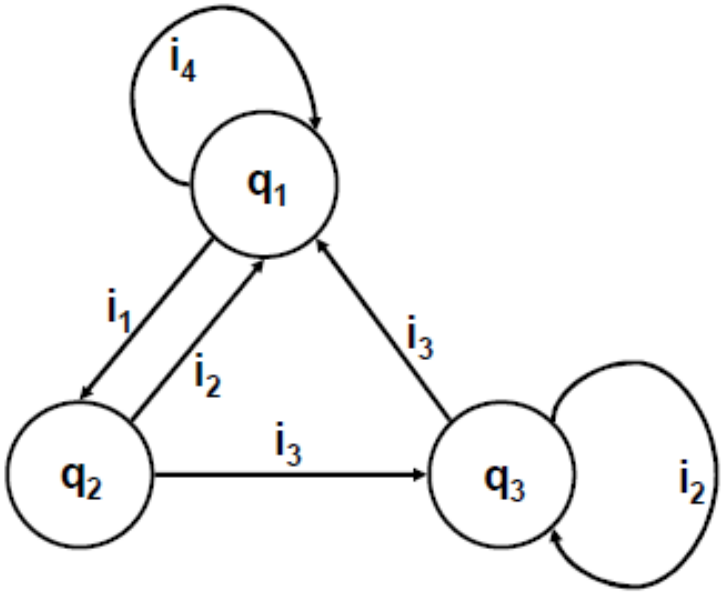
transition function δ

	i_1	i_2	i_3	i_4
q_1	q_2			q_1
q_2		q_1	q_3	
q_3		q_3	q_1	

Finite State Machines

Example

	i_1	i_2	i_3	i_4
q_1	q_2			q_1
q_2		q_1	q_3	
q_3		q_3	q_1	



Agenda

1. **FMS models**
   - **old-style rotary telephone model**
   - **cruise control system model**
     - **in-class exercise**

Finite State Machines

Telephone model using FSM

- **plain, old-style phone**
  - **possible states**
    - **busy, ringing, connected, dialing, on hook, off hook**
  - **user actions**
    - **change the phone state**
      - » **picking up the phone, dialing number, etc.**

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Telephone model using FSM

- **transition function**

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle							
Off hook, idle							
Dialing, off hook							
Busy, off hook							
Connected, off hook							
Ringing, on hook							

Finite State Machines

Telephone model using FSM

- **transition function**

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		**Off hook**					**Ringing**
Off hook, idle							
Dialing, off hook							
Busy, off hook							
Connected, off hook							
Ringing, on hook							

Finite State Machines

Telephone model using FSM

- **transition function**

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		**Off hook**					**Ringing**
Off hook, idle	**On hook**		**Dialing**				
Dialing, off hook							
Busy, off hook							
Connected, off hook							
Ringing, on hook							

Finite State Machines

Telephone model using FSM

- **transition function**

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		**Off hook**					**Ringing**
Off hook, idle	**On hook**		**Dialing**				
Dialing, off hook	**On hook**			**Connected**		**Busy**	
Busy, off hook							
Connected, off hook							
Ringing, on hook							

Finite State Machines

Telephone model using FSM

- **transition function**

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		**Off hook**					**Ringing**
Off hook, idle	**On hook**		**Dialing**				
Dialing, off hook	**On hook**			**Connected**		**Busy**	
Busy, off hook	**On hook**						
Connected, off hook							
Ringing, on hook							

Finite State Machines

Telephone model using FSM

- transition function

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		Off hook					Ringing
Off hook, idle	On hook		Dialing				
Dialing, off hook	On hook			Connected		Busy	
Busy, off hook	On hook						
Connected, off hook	On hook				Busy		
Ringing, on hook							

Finite State Machines

Telephone model using FSM

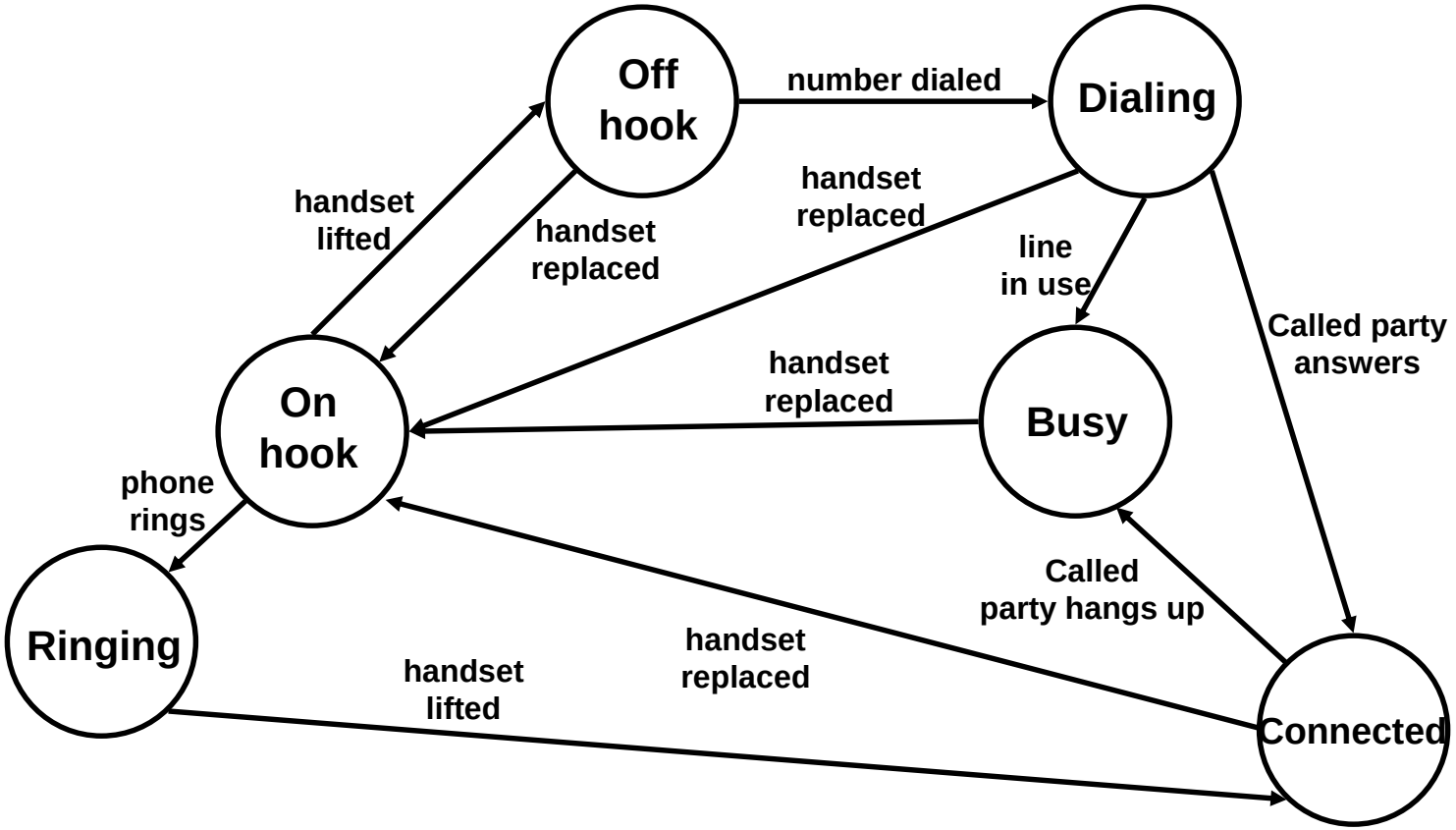
- **transition function**

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		Off hook					Ringing
Off hook, idle	On hook		Dialing				
Dialing, off hook	On hook			Connected		Busy	
Busy, off hook	On hook						
Connected, off hook	On hook				Busy		
Ringing, on hook		Connected					

	handset replaced	handset lifted	number dialed	Called party answers	Called party hangs up	line in use	phone rings
On hook, idle		Off hook					Ringing
Off hook, idle	On hook		Dialing				
Dialing, off hook	On hook			Connected		Busy	
Busy, off hook	On hook						
Connected, off hook	On hook				Busy		
Ringing, on hook		Connected					

Finite State Machines

Telephone model using FSM



Finite State Machines

Cruise-control system (CCS) model using FSM

- CCS used to automatically maintain speed of a car
- Pressing brake causes that the system to temporarily revert to manual control until resume is pressed
- CCS can be directed to increase or decrease speed to reach a new maintenance speed
- System Inputs:
  - Engine ON/OFF (CCS only active if the engine is ON)
  - Pulses (generated every revolution of the wheel)
  - Accelerator (accelerator has been pressed)
  - Brake (brake has been pressed)
  - CCS ON/OFF
  - Increase/Decrease maintained speed (only if CCS is ON)
  - Resume (resume the last maintained speed; only if CCS is ON)
- System Output:
  - Throttle (setting for engine throttle)

Finite State Machines

CCS model using FSM

- Definition of the system states:
  - Current engine status: ON/OFF
  - Current CCS status: ON/OFF
  - Current status of the throttle
    - same (throttle does not change, CCS is ON)
    - increase (throttle opens , CCS is ON)
    - decrease (throttle closes , CCS is ON)
    - manual (CCS is OFF, driver has control over the car)
      - » outside of the model scope
  - The CCS maintains the speed: YES/NO
    - if driver presses brake then NO
    - CCS system must be on

Finite State Machines

CCS model using FSM

- Definition of the system states:
  - the situation when CCS is ON, brake was pressed (CCS does not maintain the speed), and the throttle is in same position is not considered
    - the driver would need to keep pressing acceleration with power that does not change the throttle
  - there is no oscillations due to the control mechanism of the CCS
    - e.g. driving uphill CCS system would increase throttle, but would not go over the desired speed

Finite State Machines

CCS model using FSM

- Definition of the system states:

State	Engine	CCS	Throttle	CCS maintains speed
S1	off	off	same	no
S2	on	off	manual	no
S3	on	on	same	yes
S4	on	on	increase	yes
S5	on	on	decrease	yes
S6	on	on	increase	no
S7	on	on	decrease	no

Finite State Machines

inputs / states	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
	Engine ON	Engine OFF	CCS ON	CCS OFF	pulses above desired frequency	pulses below desired frequency	pulses at desired frequency	acceler down	brake	increase speed for CCS	decrease speed for CCS	resume CCS control
S1												
S2												
S3												
S4												
S5												
S6												
S7												

Finite State Machines

Fill out the LAB report

- **group work**
- **up to 45 minutes**
- **turn it back to the instructor when finished**
- **grade will be individual (equal for every team member)**

Finite State Machines

inputs / states	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
	Engine ON	Engine OFF	CCS ON	CCS OFF	pulses above desired frequency	pulses below desired frequency	pulses at desired frequency	acceler down	brake	increase speed for CCS	decrease speed for CCS	resume CCS control
S1												
S2												
S3												
S4												
S5												
S6												
S7												

Finite State Machines

State	Engine	CCS	Throttle	CCS maintains speed
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S3	on	on	same	yes
S4	on	on	increase	yes
S5	on	on	decrease	yes
S6	on	on	increase	no
S7	on	on	decrease	no

inputs / states	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
	Engine ON	Engine OFF	CCS ON	CCS OFF	pulses above desired frequency	pulses below desired frequency	pulses at desired frequency	acceler down	brake	increase speed for CCS	decrease speed for CCS	resume CCS control
S1	S2	–	–	–	–	–	–	–	–	–	–	–
S2	–	S1	S3	–	–	–	–	S2	S2	–	–	–
S3	–	–	–	S2								
S4	–	–	–	S2								
S5	–	–	–	S2								
S6	–	S1	–	S2								
S7	–	S1	–	S2								

- engine OFF input is allowed only when car is in S2 or CCS will not maintain the speed and speed is zero (i.e. pulses with zero frequency)
- CCS is OFF is not modeled
  - abstract state in which throttle is controlled manually by the driver
- when engine is OFF then the car will not move or react to any inputs except engine ON

Finite State Machines

State	Engine	CCS	Throttle	CCS maintains speed
S1	off	off	same	no
S2	on	off	manual	no
S3	on	on	same	yes
S4	on	on	increase	yes
S5	on	on	decrease	yes
S6	on	on	increase	no
S7	on	on	decrease	no

inputs / states	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
	Engine ON	Engine OFF	CCS ON	CCS OFF	pulses above desired frequency	pulses below desired frequency	pulses at desired frequency	acceler down	brake	increase speed for CCS	decrease speed for CCS	resume CCS control
S1	S2	–	–	–	–	–	–	–	–	–	–	–
S2	–	S1	S3	–	–	–	–	S2	S2	–	–	–
S3	–	–	–	S2	S5	S4	S3					
S4	–	–	–	S2	S5	S4	S3					
S5	–	–	–	S2	S5	S4	S3					
S6	–	S1	–	S2	–	–	–					
S7	–	S1	–	S2	–	–	–					

- S4 (increasing) goes to S5 (decreasing) since we allow that the driver to accelerate while CCS maintains the speed
  - CCS system needs to slow down the car after that
  - brake causes that the CCS temporarily revert to manual control until resume is pressed
  - after stopping to press acceleration, the CCS decreases the cars speed using the I5 input (pulses frequency above the desired frequency)

Finite State Machines

State	Engine	CCS	Throttle	CCS maintains speed
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S2	on	off	manual	no
S3	on	on	same	yes
S4	on	on	increase	yes
S5	on	on	decrease	yes
S6	on	on	increase	no
S7	on	on	decrease	no

inputs / states	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
	Engine ON	Engine OFF	CCS ON	CCS OFF	pulses above desired frequency	pulses below desired frequency	pulses at desired frequency	acceler down	brake	increase speed for CCS	decrease speed for CCS	resume CCS control
S1	S2	–	–	–	–	–	–	–	–	–	–	–
S2	–	S1	S3	–	–	–	–	S2	S2	–	–	–
S3	–	–	–	S2	S5	S4	S3	S4	S7			–
S4	–	–	–	S2	S5	S4	S3	S4	S7			–
S5	–	–	–	S2	S5	S4	S3	S4	S7			–
S6	–	S1	–	S2	–	–	–	S6	S7			S3
S7	–	S1	–	S2	–	–	–	S6	S7			S3

- brake causes that the CCS temporarily revert to manual control (S7) until resume is pressed
- when CCS does not maintain the speed (S6 or S7) and resume is pressed, the system goes to S3 (CCS is set ON) and adjusts the speed using the value of desired frequency of pulses and inputs I5 or I6

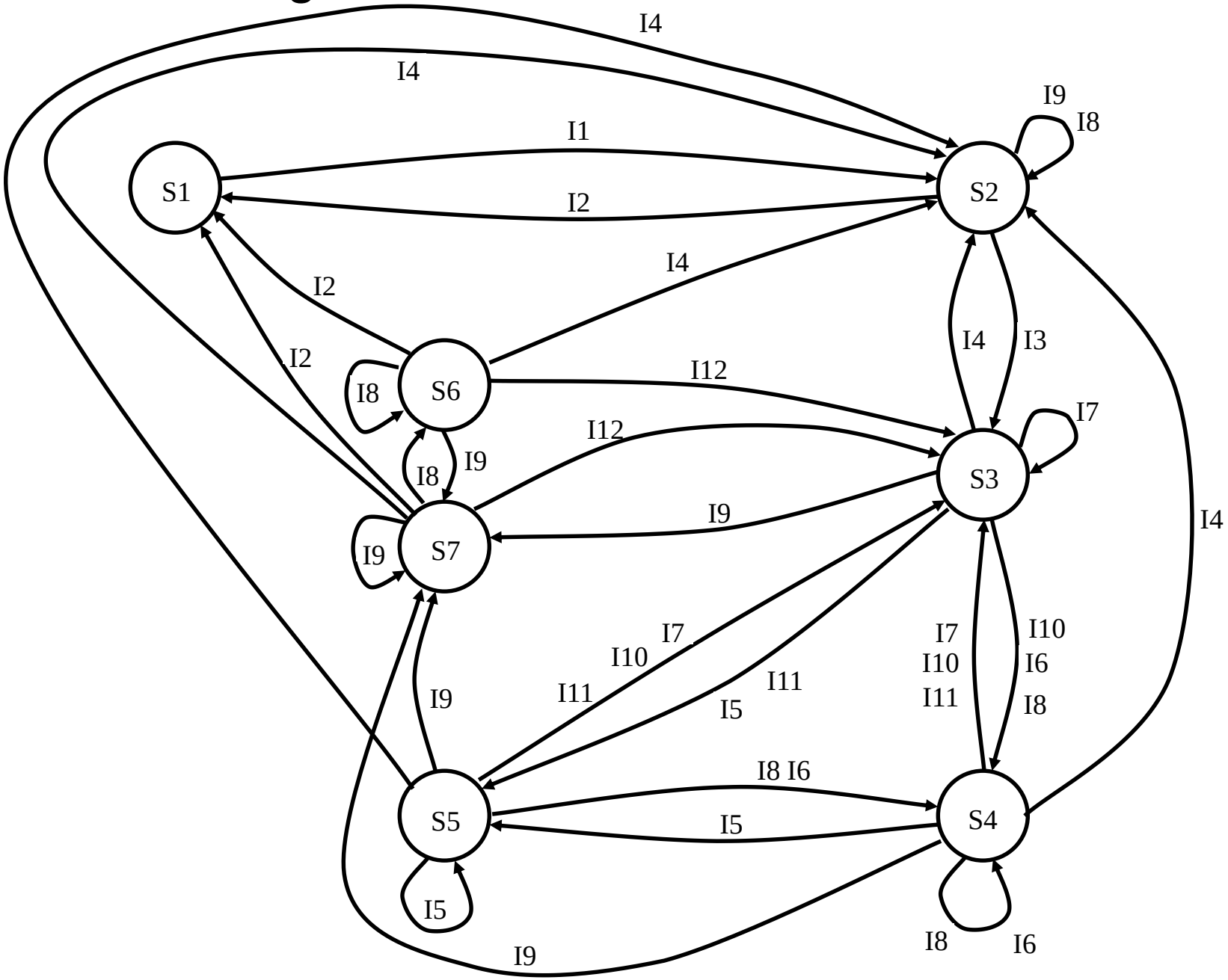
Finite State Machines

State	Engine	CCS	Throttle	CCS maintains speed
S1	off	off	same	no
S2	on	off	manual	no
S3	on	on	same	yes
S4	on	on	increase	yes
S5	on	on	decrease	yes
S6	on	on	increase	no
S7	on	on	decrease	no

inputs / states	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
	Engine ON	Engine OFF	CCS ON	CCS OFF	pulses above desired frequency	pulses below desired frequency	pulses at desired frequency	acceler down	brake	increase speed for CCS	decrease speed for CCS	resume CCS control
S1	S2	–	–	–	–	–	–	–	–	–	–	–
S2	–	S1	S3	–	–	–	–	S2	S2	–	–	–
S3	–	–	–	S2	S5	S4	S3	S4	S7	S4	S5	–
S4	–	–	–	S2	S5	S4	S3	S4	S7	S3	S3	–
S5	–	–	–	S2	S5	S4	S3	S4	S7	S3	S3	–
S6	–	S1	–	S2	–	–	–	S6	S7	–	–	S3
S7	–	S1	–	S2	–	–	–	S6	S7	–	–	S3

- when increasing or decreasing speed for CCS and when the CCS system is currently adjusting the car speed to reach the previously desired speed, leads to the S3 state (keep same throttle)
  - the desired frequency of pulsed is changed
  - based on the I5 or I6, the system would adjust the speed to the new desired speed.

CCS model using FSM



Homework and Next Time

prepare yourself for the next LAB

- **review the Petri Nets theory**
  - **next time you will learn a software tool for drawing and simulating Petri Nets**