Systems Design Laboratory

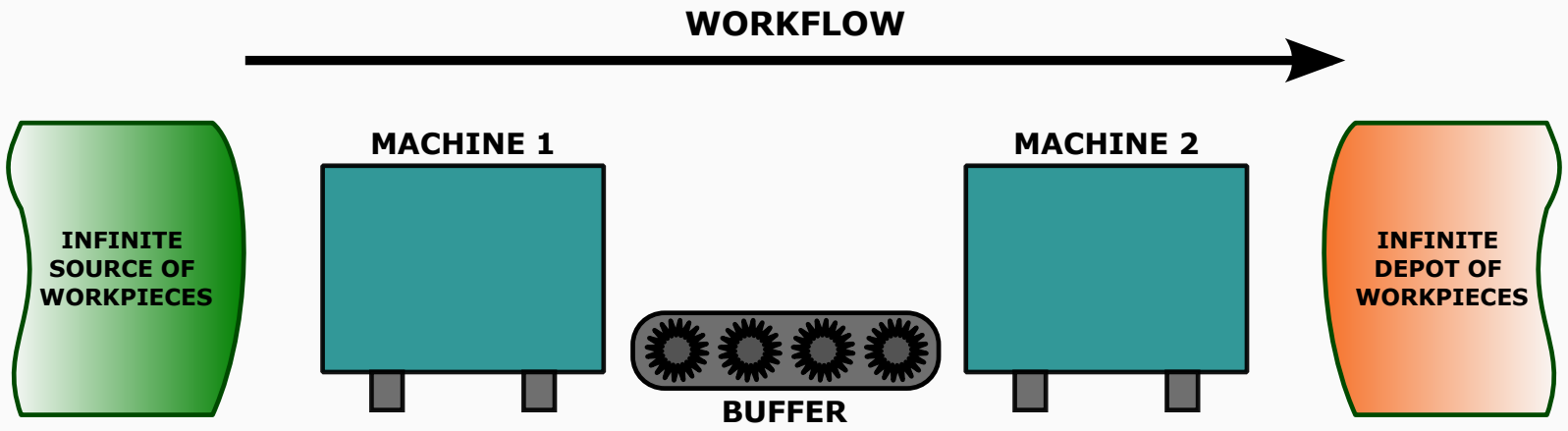
A Manufacturing Process

Matteo Zavatteri

[1]Department of Mathematics, University of Padova, ITALY

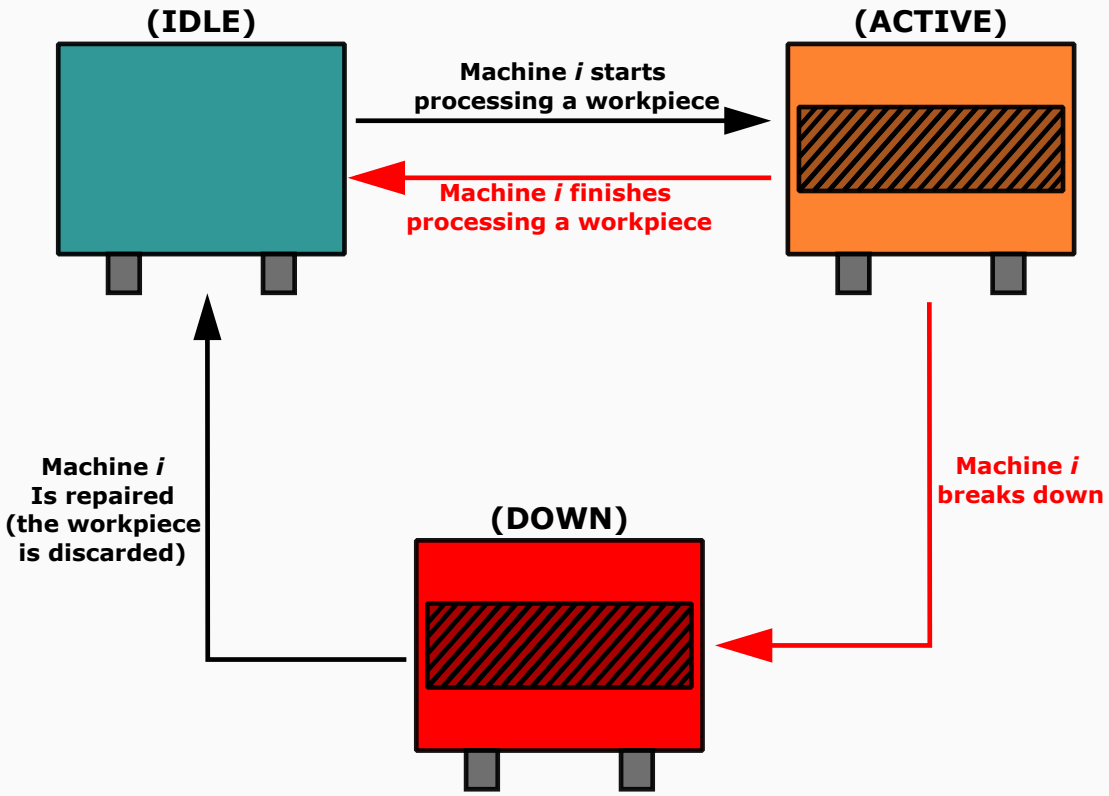
[2]Department of Computer Science, University of Verona, ITALY

A Manufacturing Process



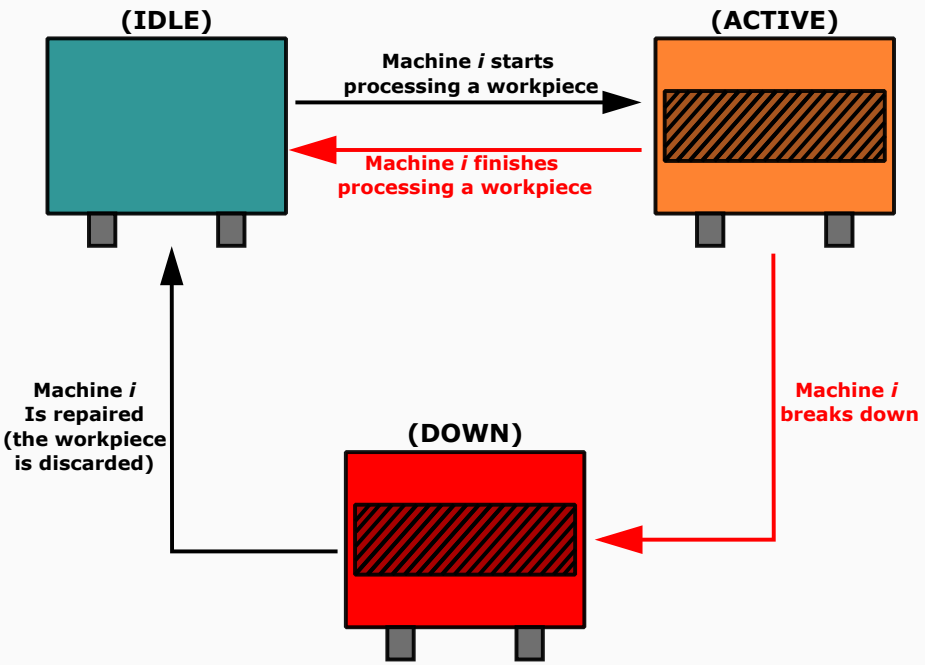
- The workflow is intended "left to right"
- Two machines processing workpieces
  - Machine 1 has an infinite source of workpieces
  - Machine 2 has an infinite depot of workpieces
- A Buffer (e.g., a conveyor) passing workpieces from Machine 1 to Machine 2

Machine $i = 1, 2$



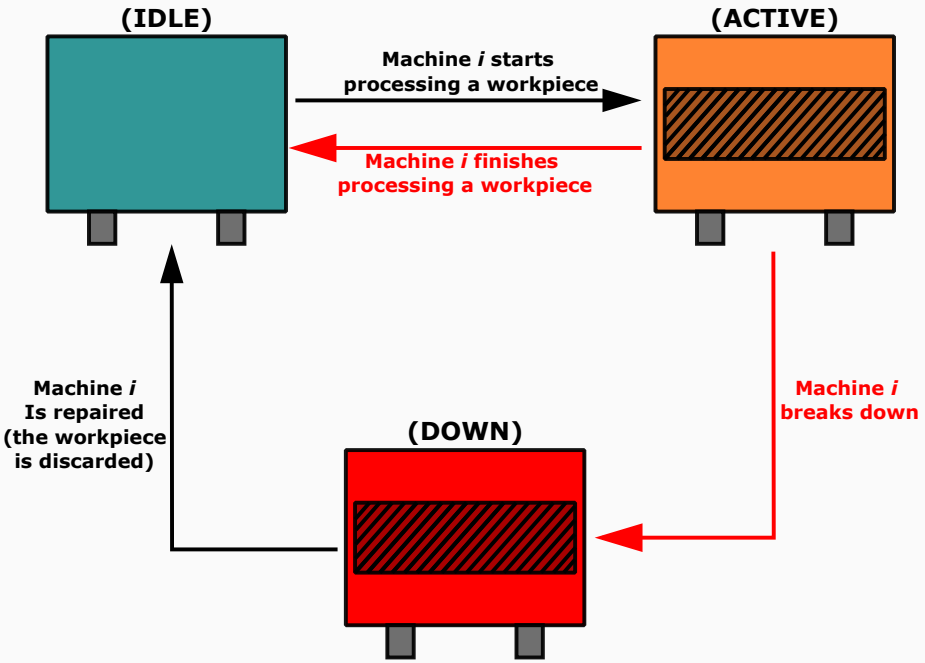
- Machine i starts and finishes processing workpieces (exactly like the Machine-Warehouse example)
- Machine i can also break down. If it does, it can be repaired and the workpiece being processed is discarded
- Machine i can't be prevented from finishing or breaking (why?)
- Initially, Machine i is IDLE.

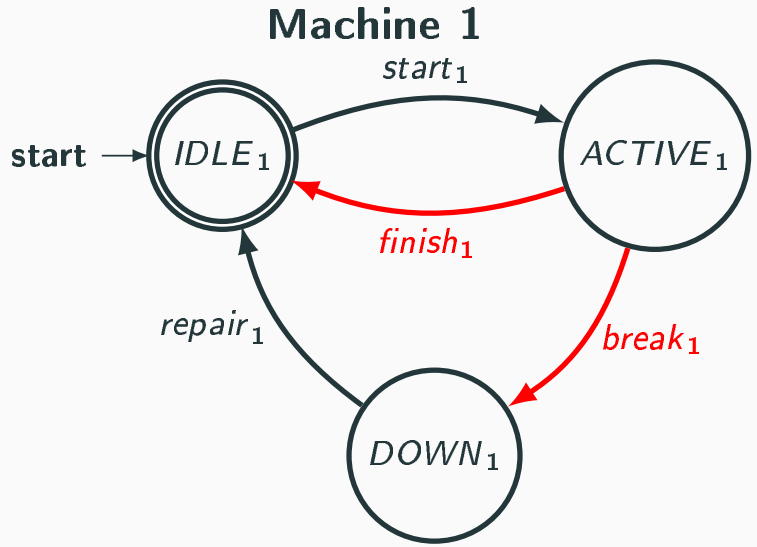
Automaton for Machine $i = 1, 2$

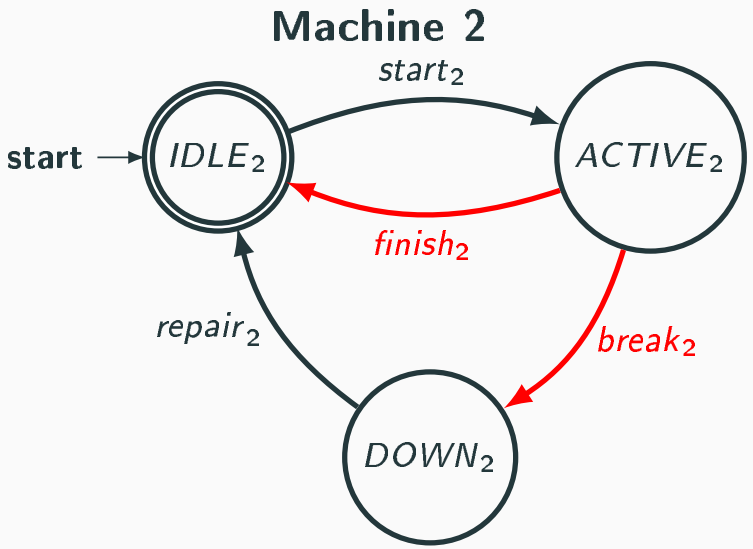


- States?
- Transitions?
- Event controllability?

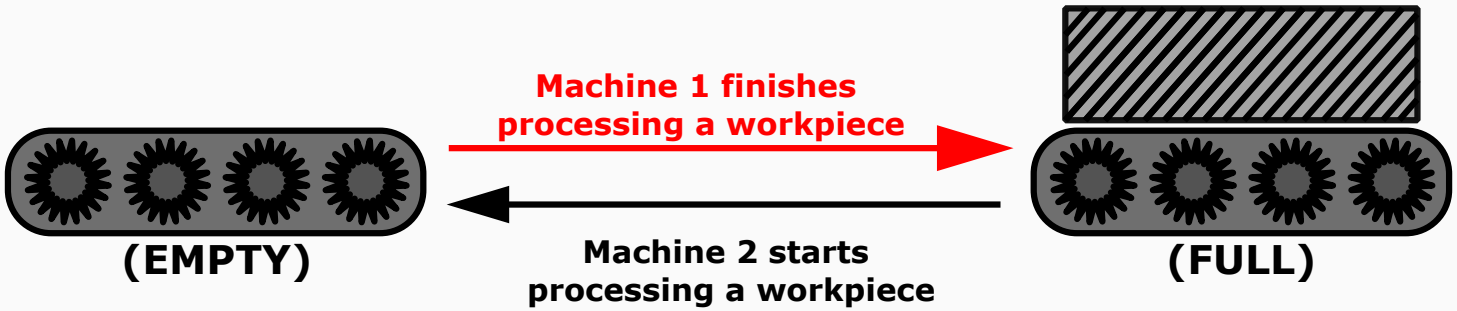
Automaton for Machine $i = 1, 2$







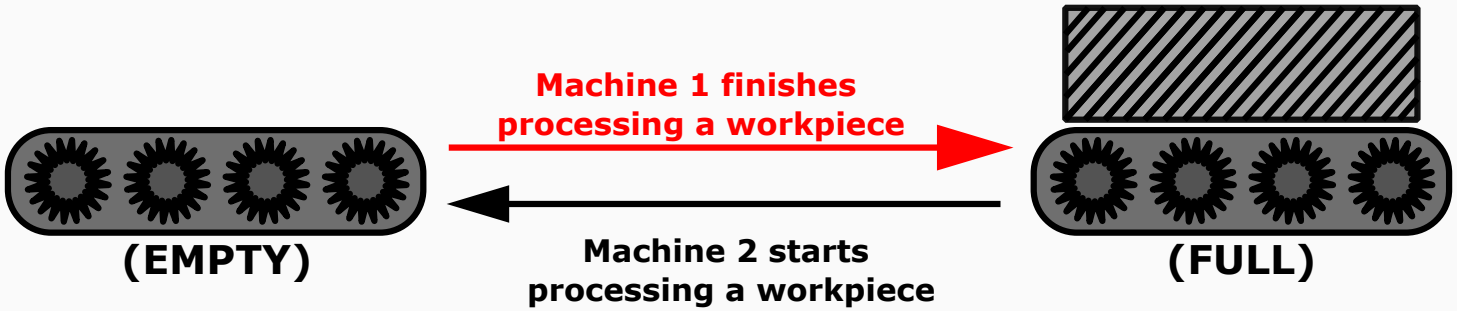
Buffer B



- Buffer has a capacity of 1 workpieces
- Buffer is synchronized with Machine 1 and Machine 2
- Buffer fills when Machine 1 finishes processing a workpiece
- Buffer empties when Machine 2 starts processing a workpiece
- Initially, the Buffer is empty

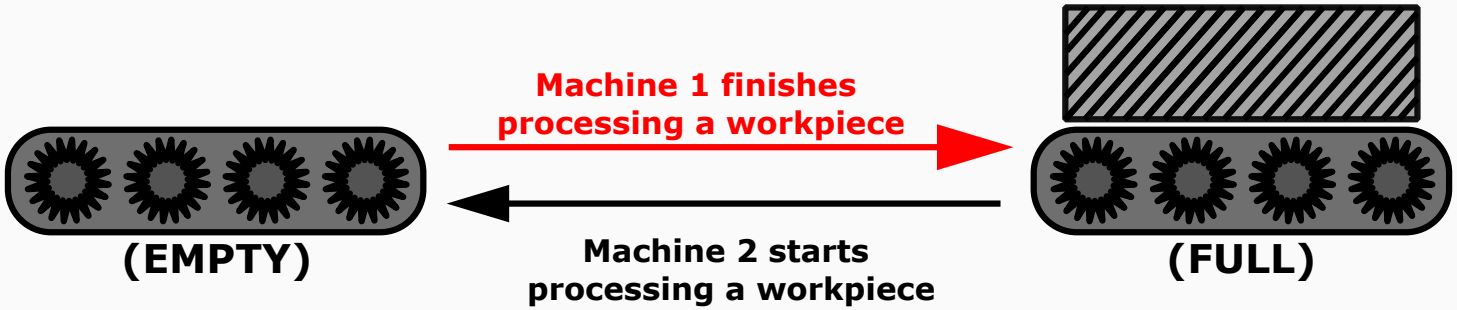
In other words, Machine 1 puts workpieces on the buffer, whereas Machine 2 removes workpieces from the buffer

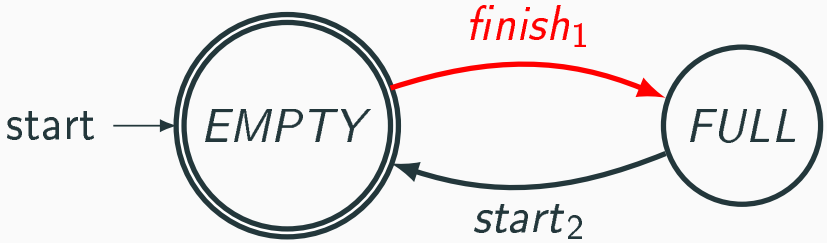
Automaton for Buffer B



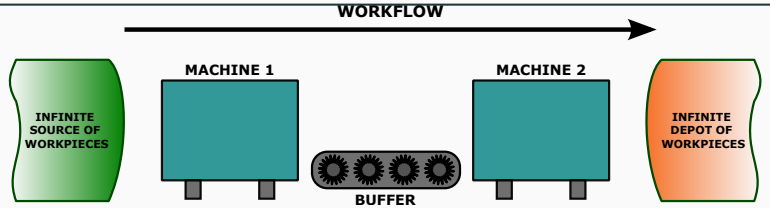
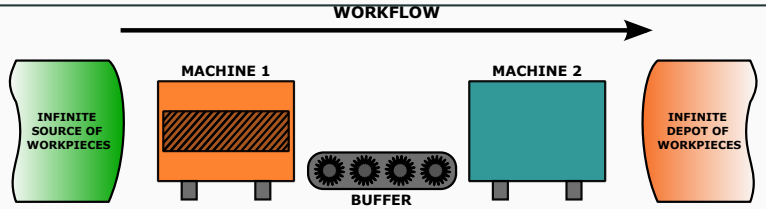
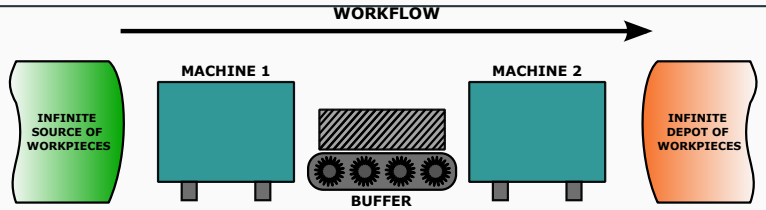
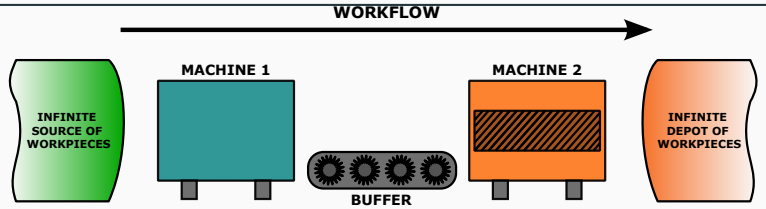
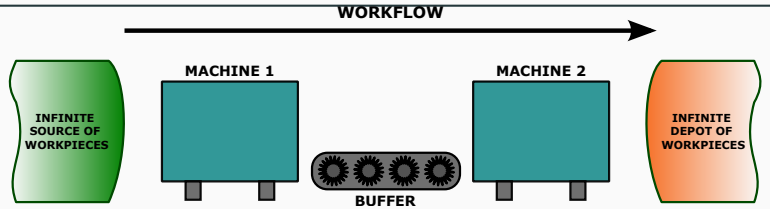
- States?
- Transitions?
- Event controllability?

Automaton for Buffer B

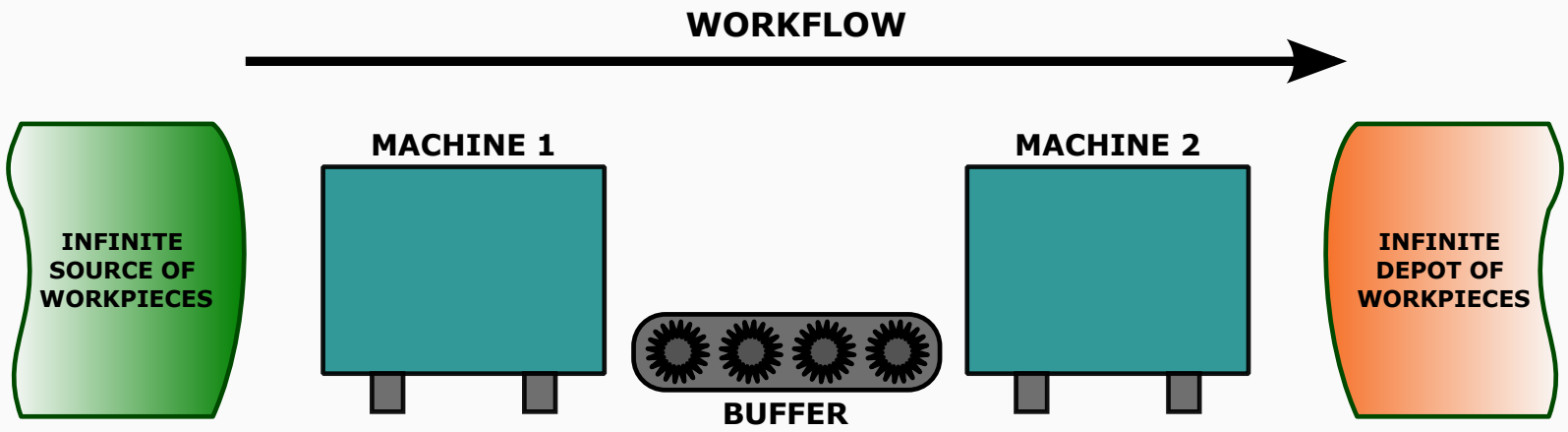




A Manufacturing Process - Usecase Example

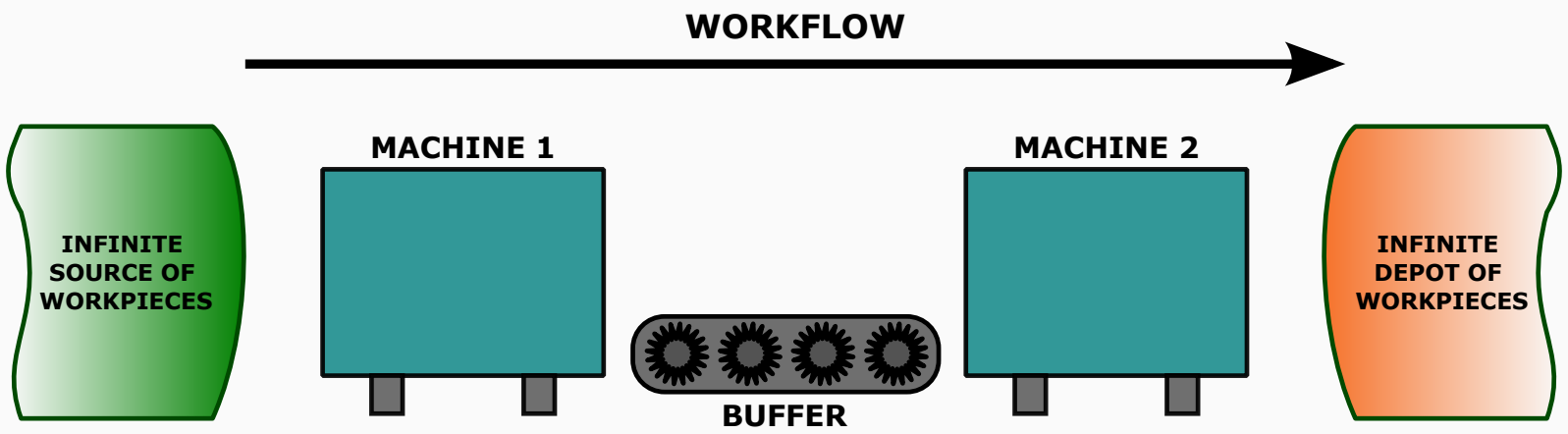
Graphical Representation	Description
	Whole system is idle
	M_1 starts processing a workpiece
	M_1 finishes processing the workpiece
	M_2 starts processing the workpiece
	M_2 finishes processing the workpiece

What about source and depot?

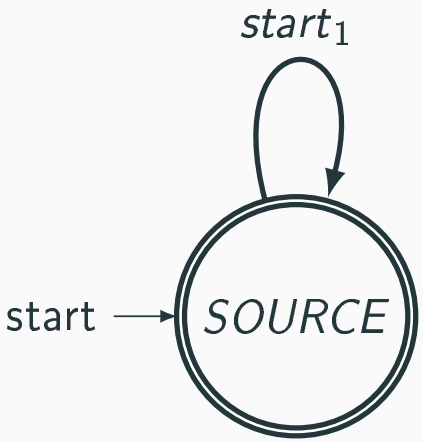


- Can you think about two automata to model them?
- States?
- Transitions?
- Event controllability?

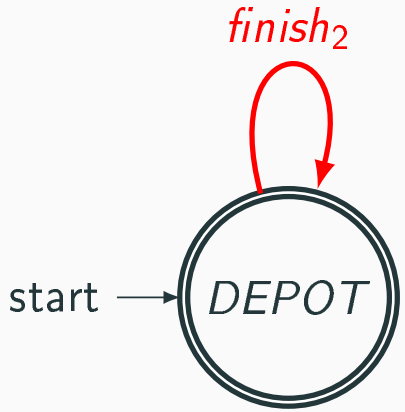
What about source and depot?



Source

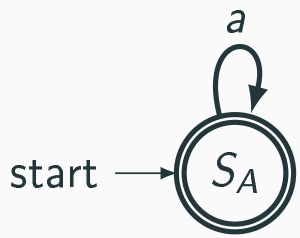
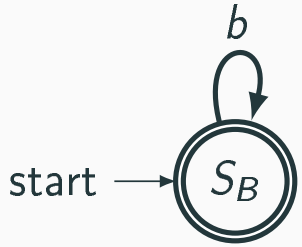
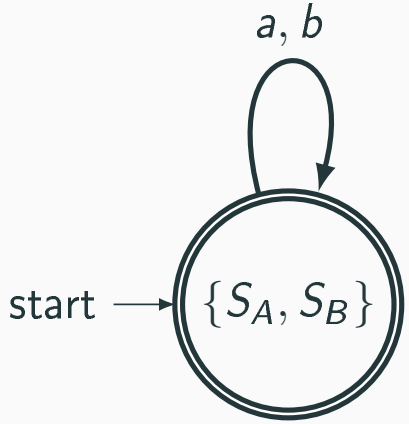
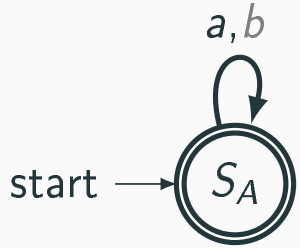
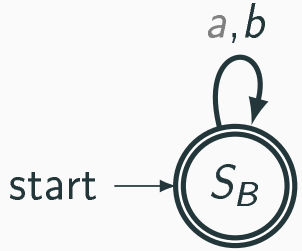
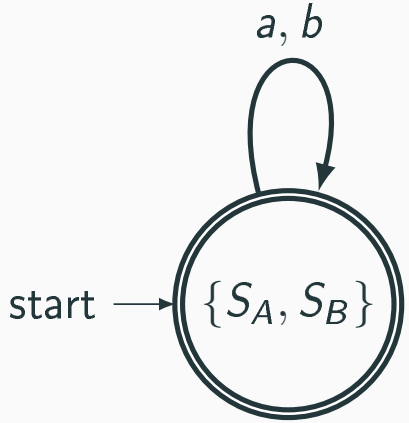


Depot

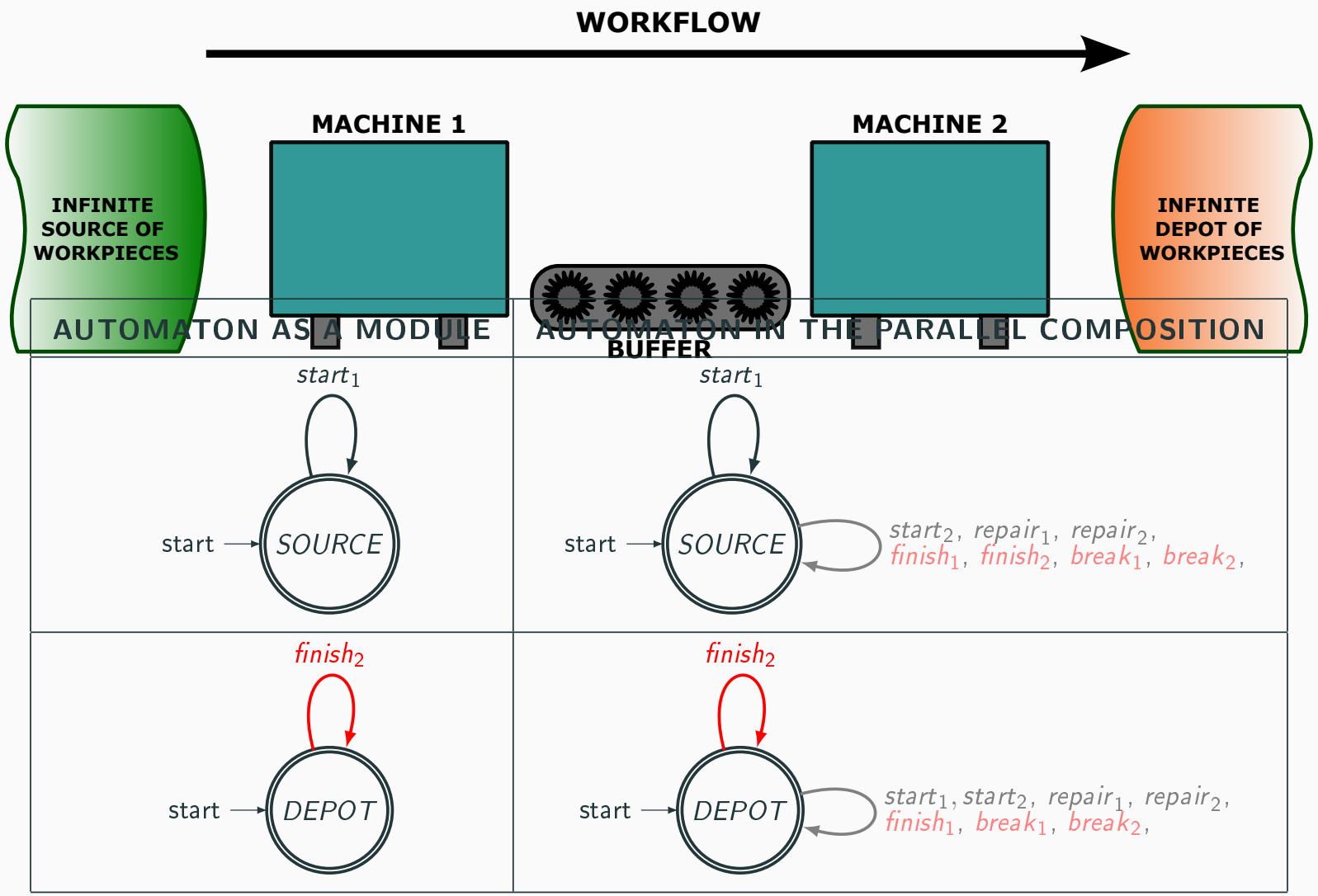


Do we really need them?

Recall on the Equivalence Between Parallel and Product

Automaton A	**Automaton** B	**Automaton** $A \| B$
 $\Sigma_A := \{a\}$	 $\Sigma_B := \{b\}$	 $\Sigma_{A\|B} := \Sigma_A \cup \Sigma_B = \{a, b\}$
Automaton A'	**Automaton** B'	**Automaton** $A' \times B'$
 $\Sigma_{A'} := \{a, b\}$	 $\Sigma_{B'} := \{a, b\}$	 $\Sigma_{A' \times B'} := \Sigma_{A'} \cup \Sigma_{B'} = \{a, b\}$

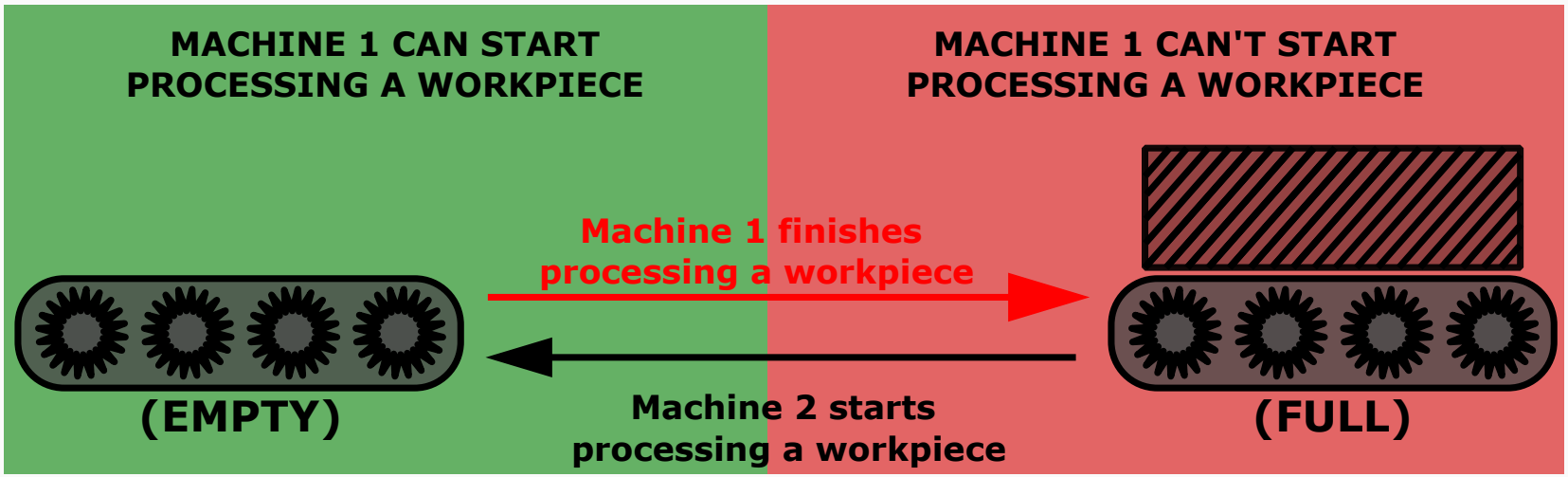
What about source and depot?



(Σ^*). Thus, we do not need them.

Requirement R_1 - Essential Desired Behavior

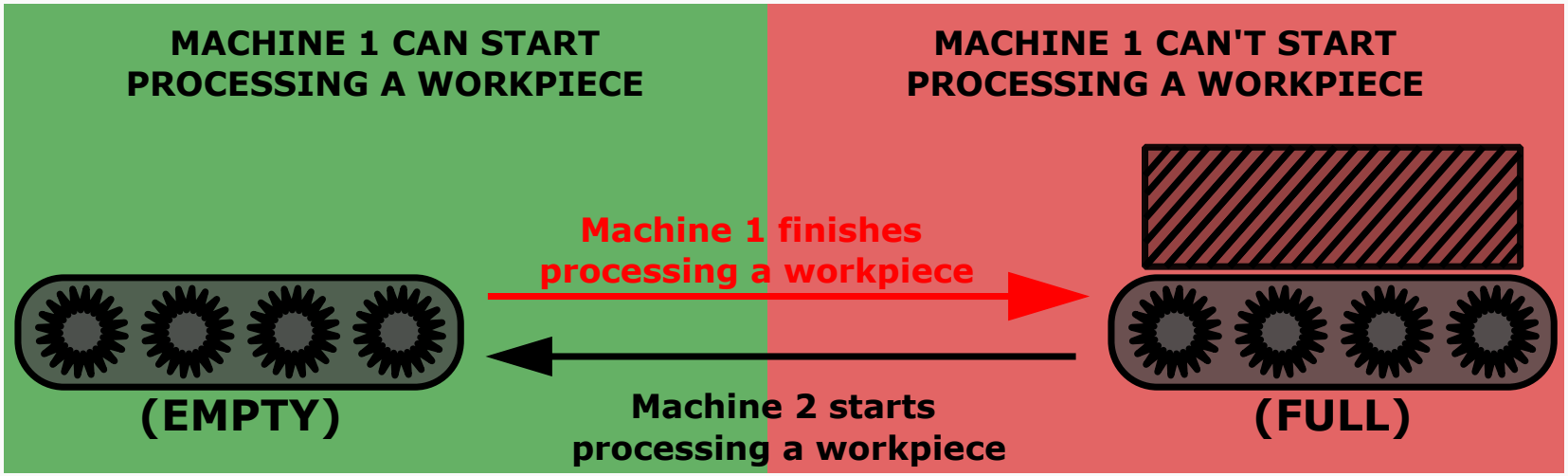
Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty

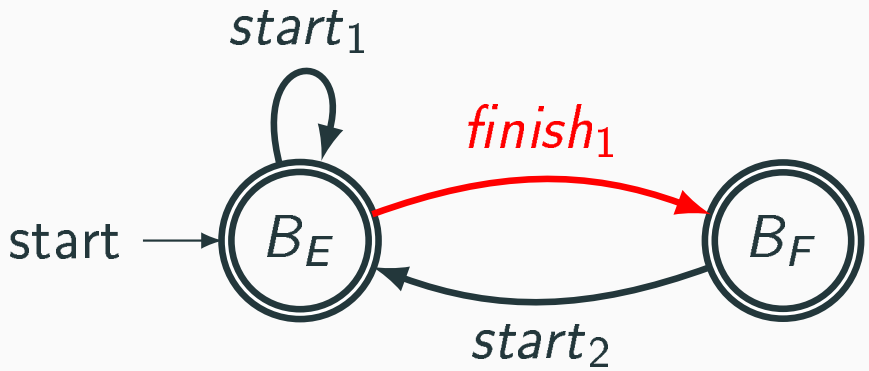


What should the automaton look like?

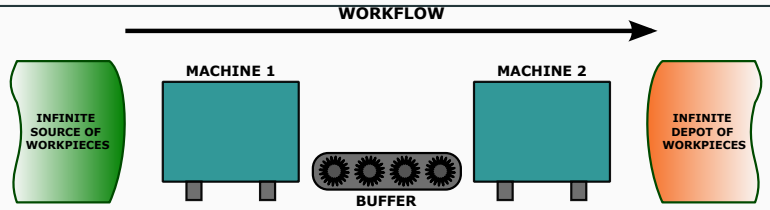
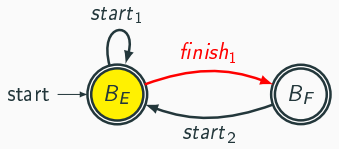
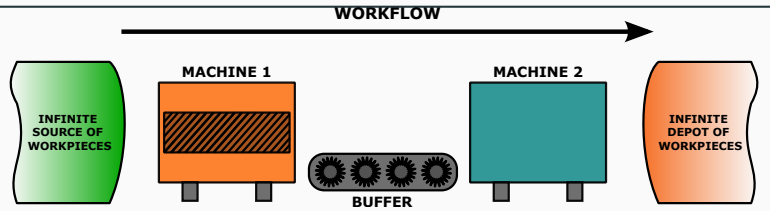
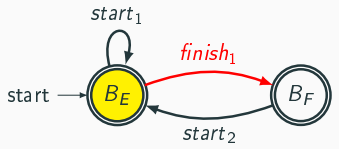
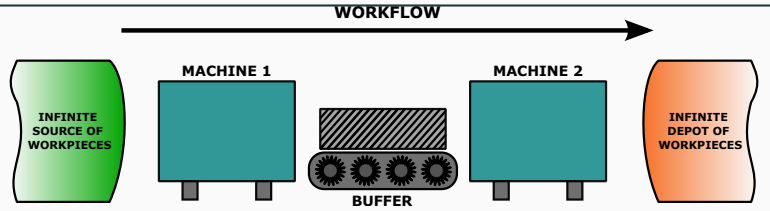
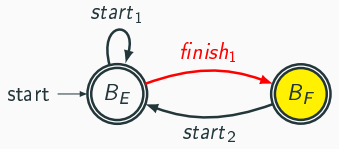
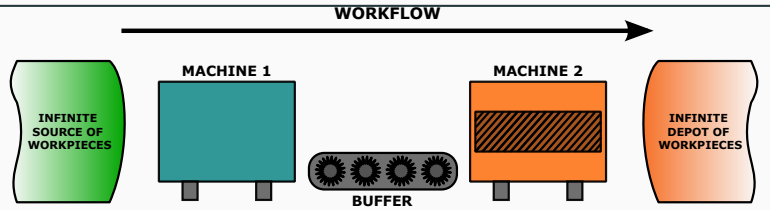
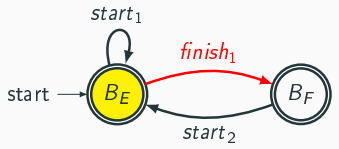
Requirement R_1 - Essential Desired Behavior

Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty

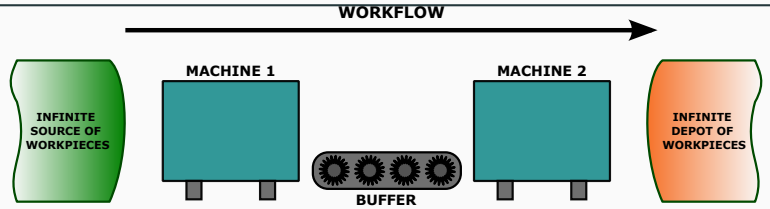
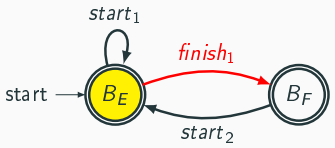
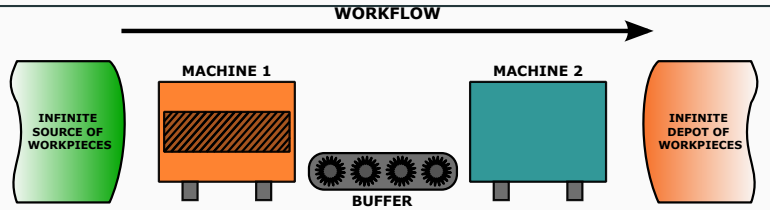
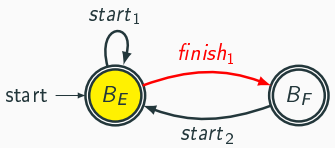
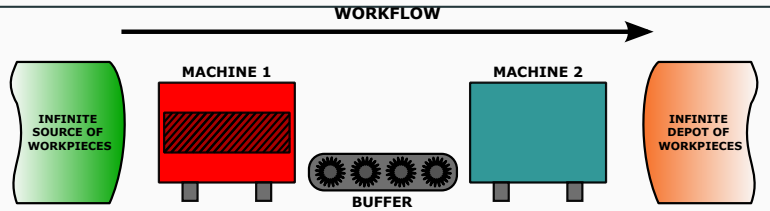
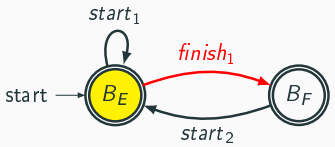
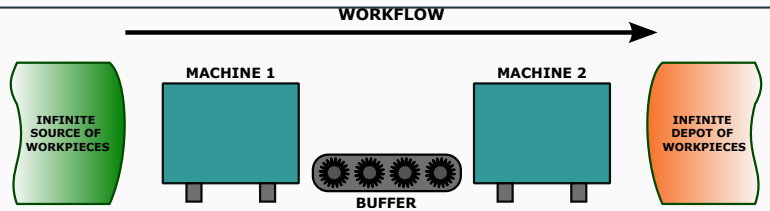
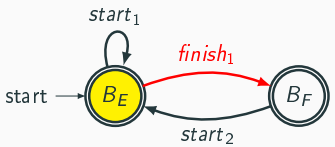




Requirement R_1 - Usecase 1

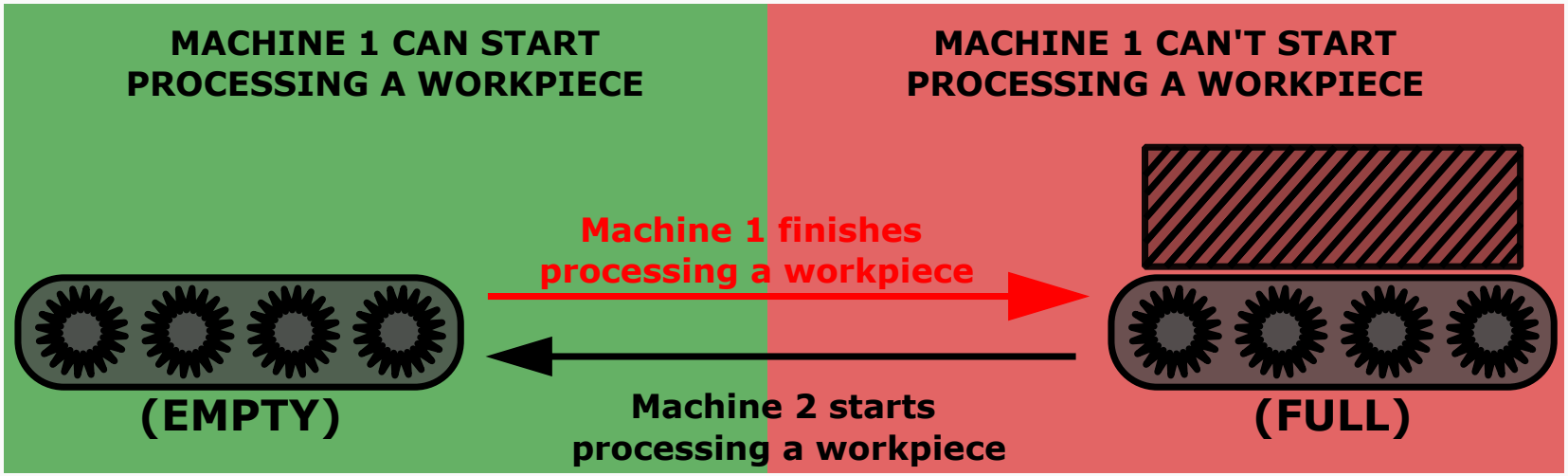
Graphical Representation	Requirement	Description
		Whole system is idle
		M_1 starts processing a workpiece
		M_1 finishes processing the workpiece
		M_2 starts processing the workpiece

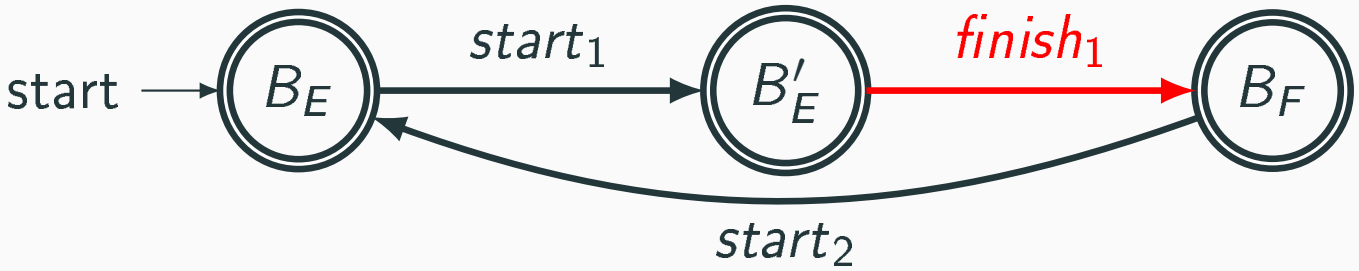
Requirment R_1 - Usecase 2

Graphical Representation	Requirement	Description
		Whole system is idle
		M_1 starts processing a workpiece
		M_1 breaks down
		M_1 is repaired and it can start again

What about this version for R_1? Right or wrong?

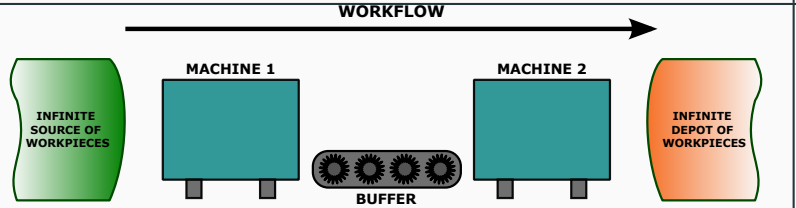
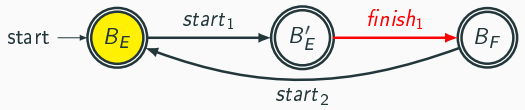
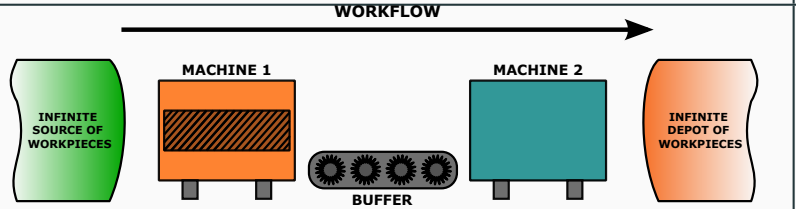
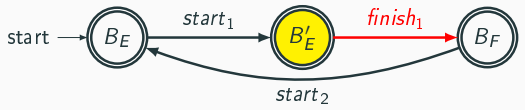
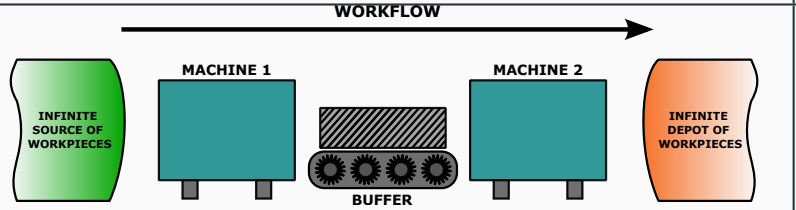
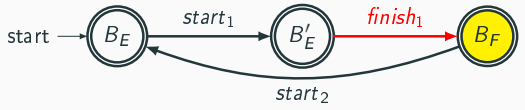
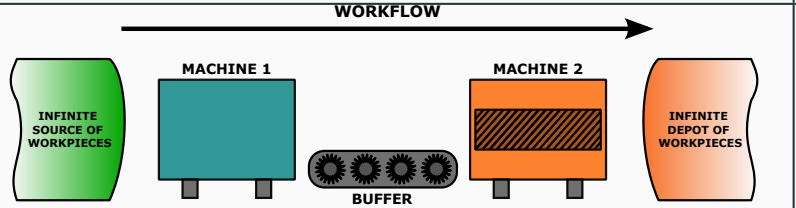
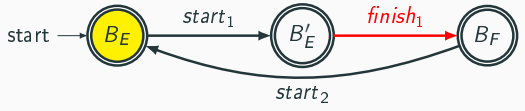
Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty





Could this be another automaton modeling R_1?

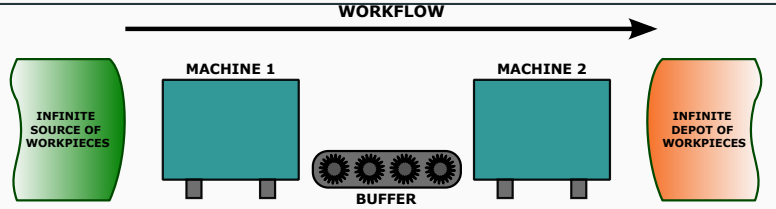
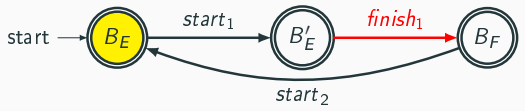
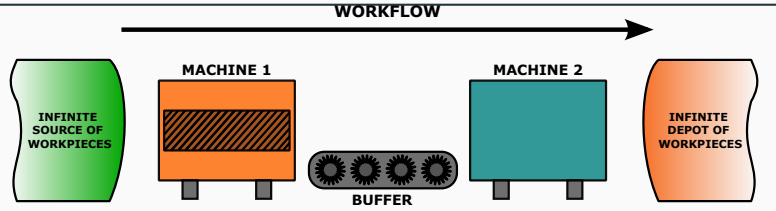
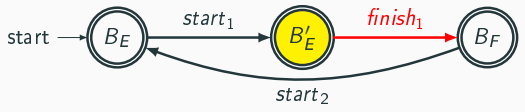
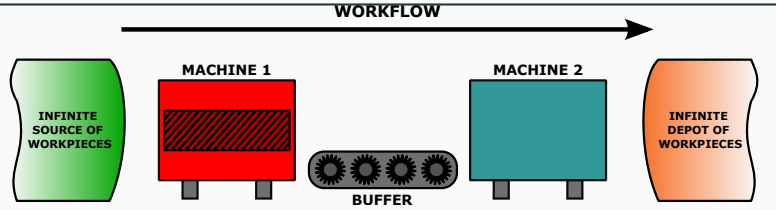
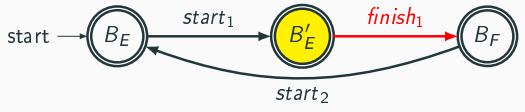
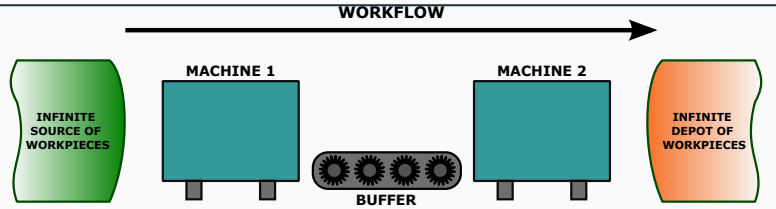
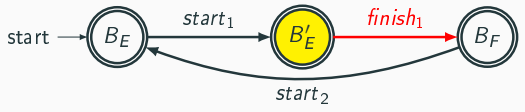
Right or wrong? - Usecase 1

		**Whole system is idle**
		M_1 **starts processing a workpiece**
		M_1 **finishes processing the workpiece**
		M_2 **starts processing the workpiece**

Seems working, right?

...right?

Right or wrong? - Usecase 2

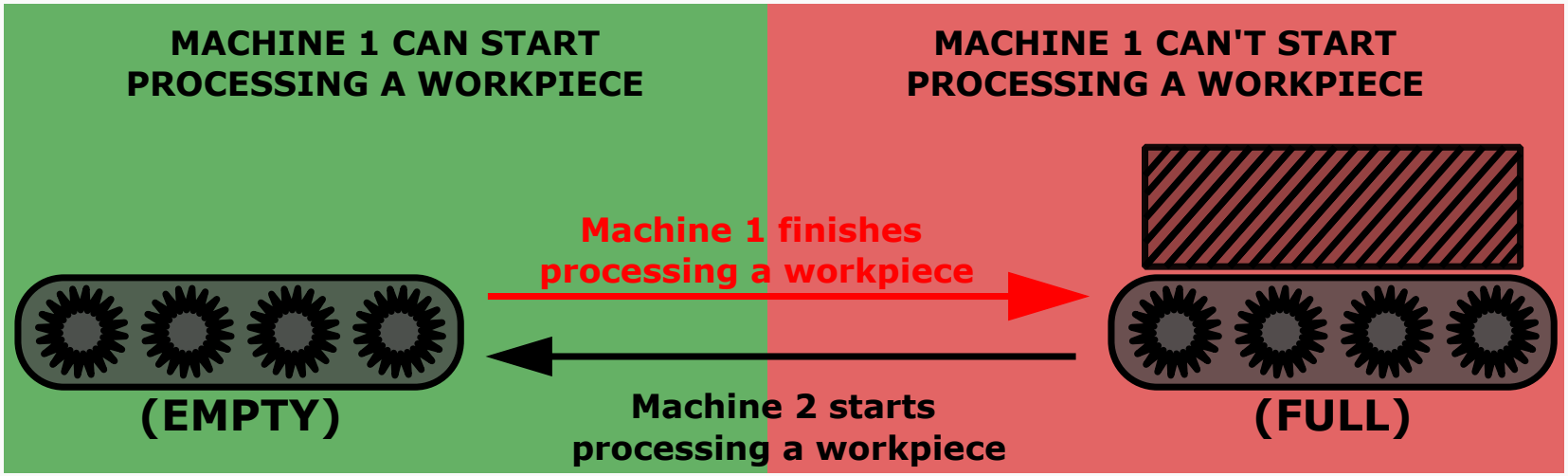
		**Whole system is idle**
		M_1 **starts processing a workpiece**
		M_1 **breaks down**
		M_1 **is repaired and it cannot start again**

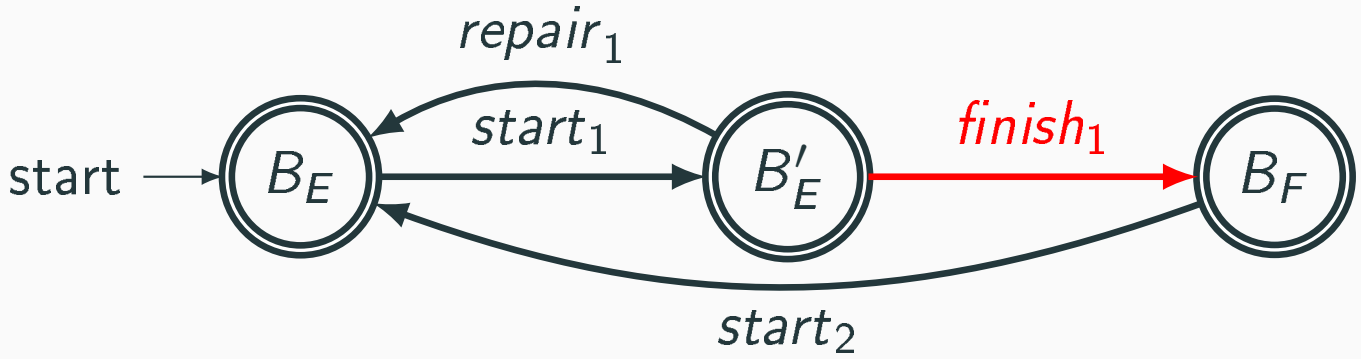
Wrong! But still OK if Machine 1 never breaks (Usecase 1)

What's missing?

Alternative R_1

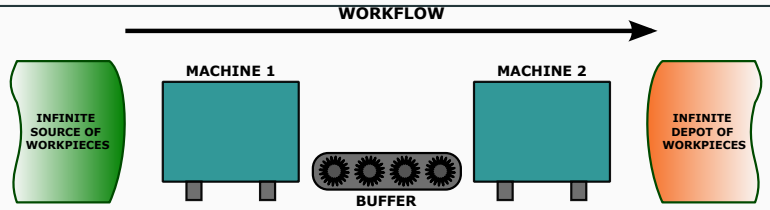
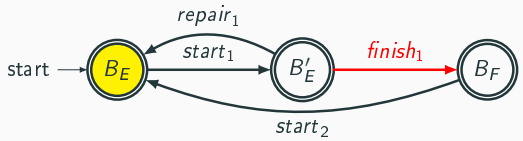
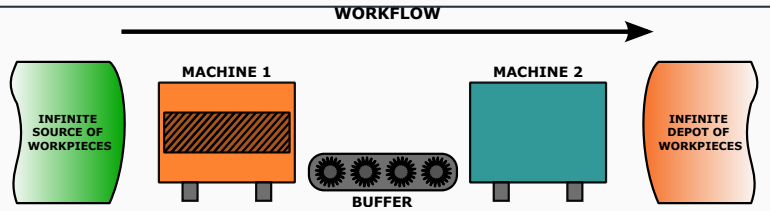
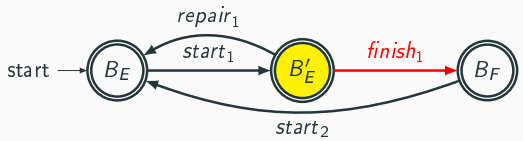
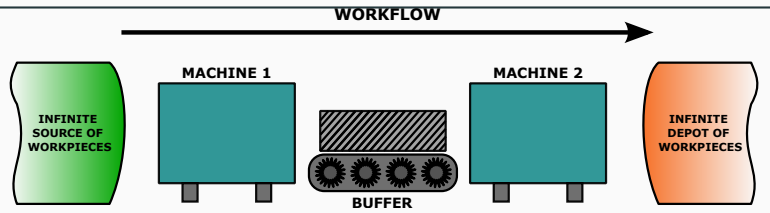
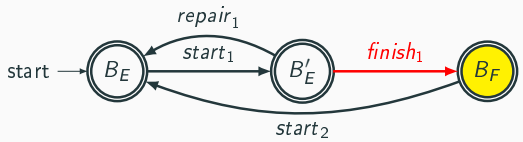
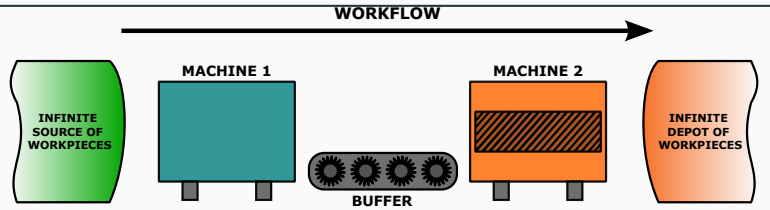
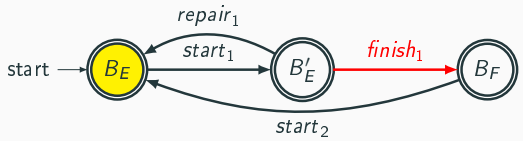
Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty



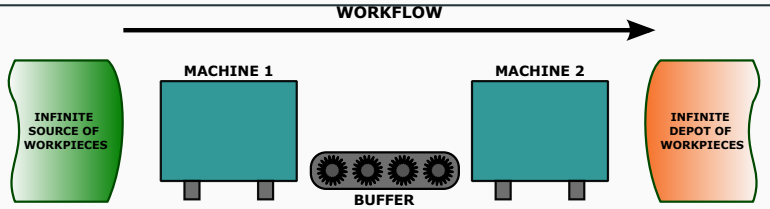
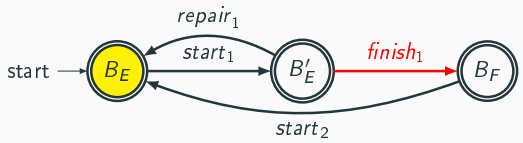
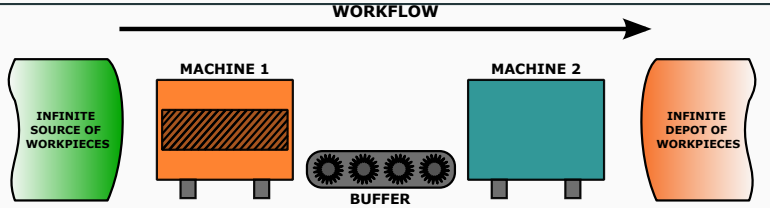
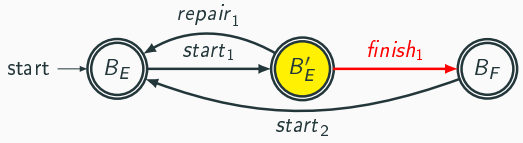
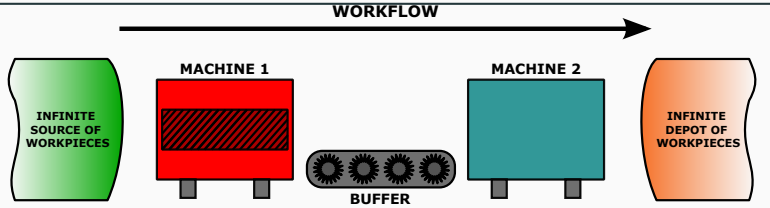
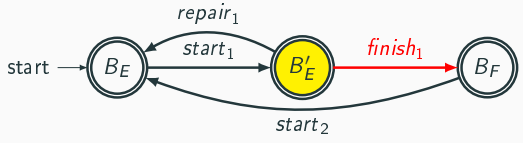
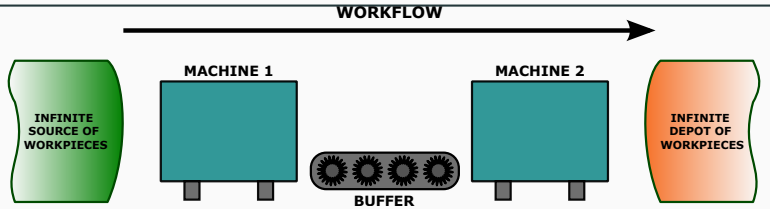
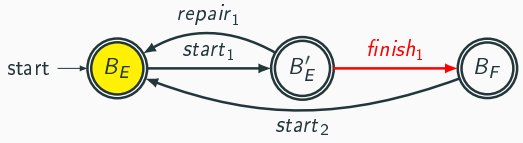


Right! Can we simplify it?

Alternative R_1 - Usecase 1

Graphical Representation	Requirement	Description
		Whole system is idle
		M_1 starts processing a workpiece
		M_1 finishes processing the workpiece
		M_2 starts processing the workpiece

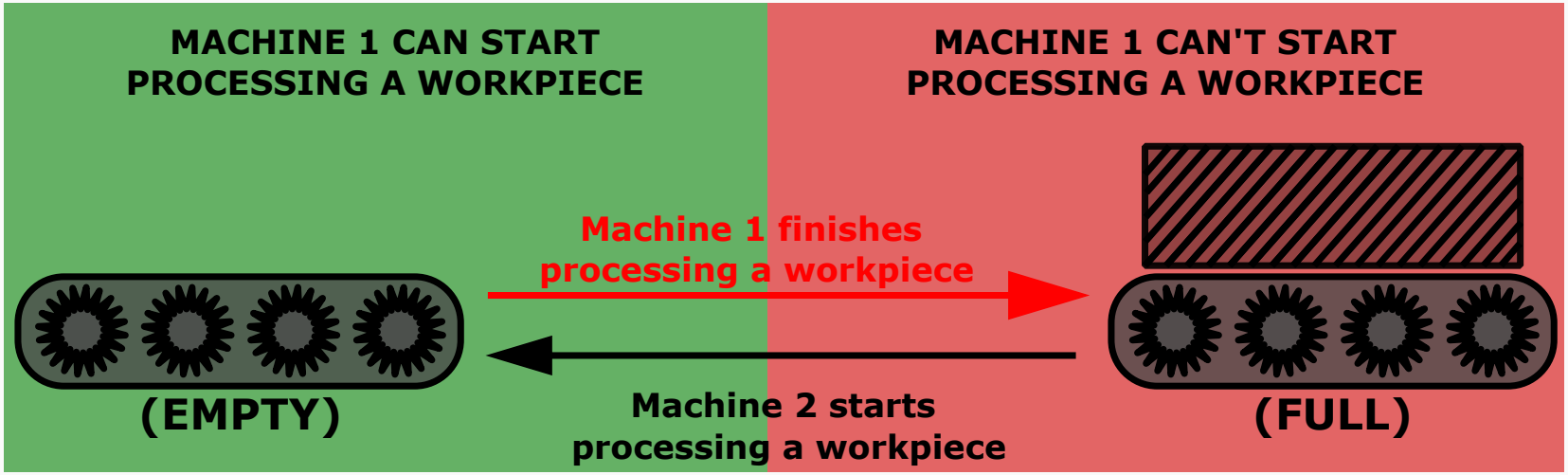
Alternative R_1 - Usecase 2

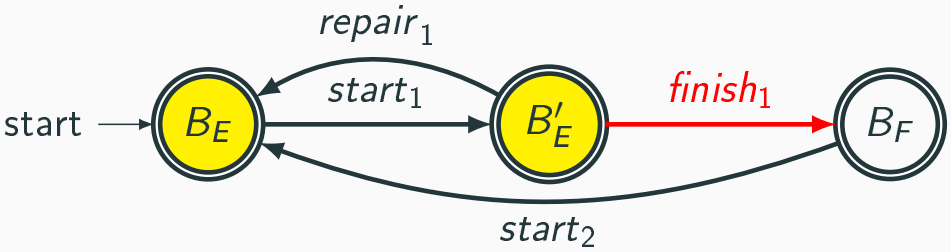
Graphical Representation	Requirement	Description
		Whole system is idle
		M_1 starts processing a workpiece
		M_1 breaks down
		M_1 is repaired and it can start again

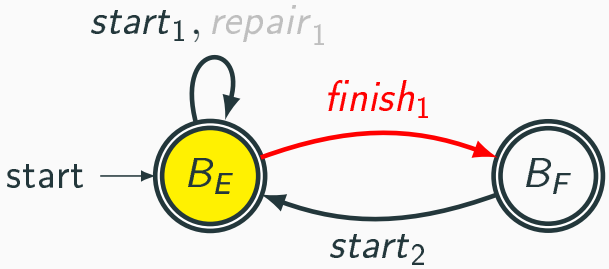
Correct! Can we simplify the requirement?

Alternative R_1 - Simplification

Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty



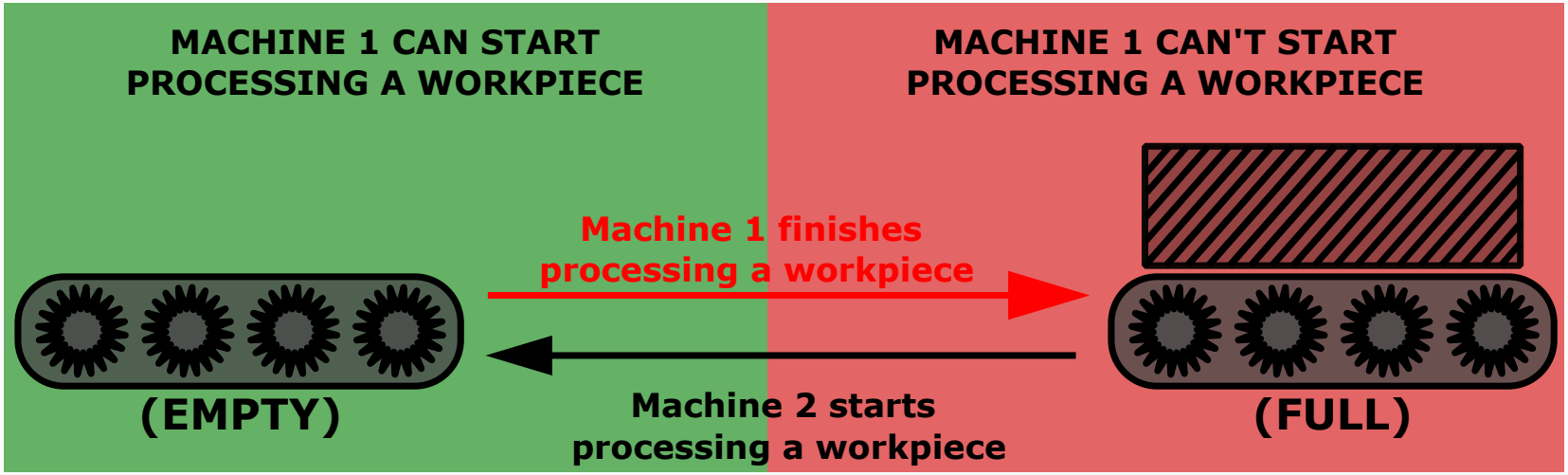


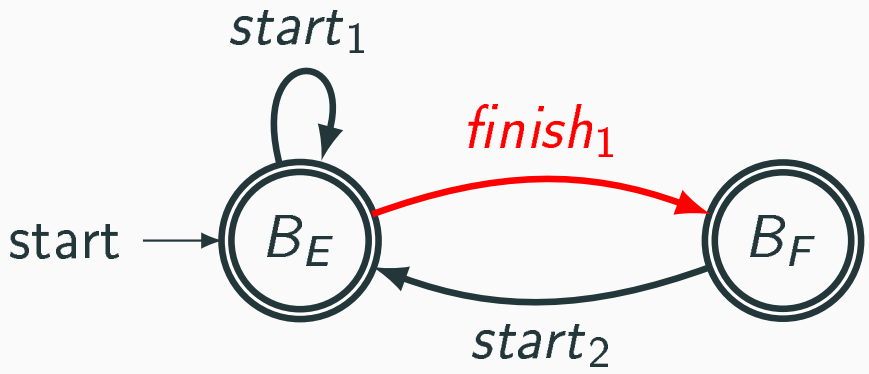


Can Machine 1 be repaired if it can't even start?
(=can we further simplify the requirement?)

Requirement R_1 - Essential Desired Behavior

Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty

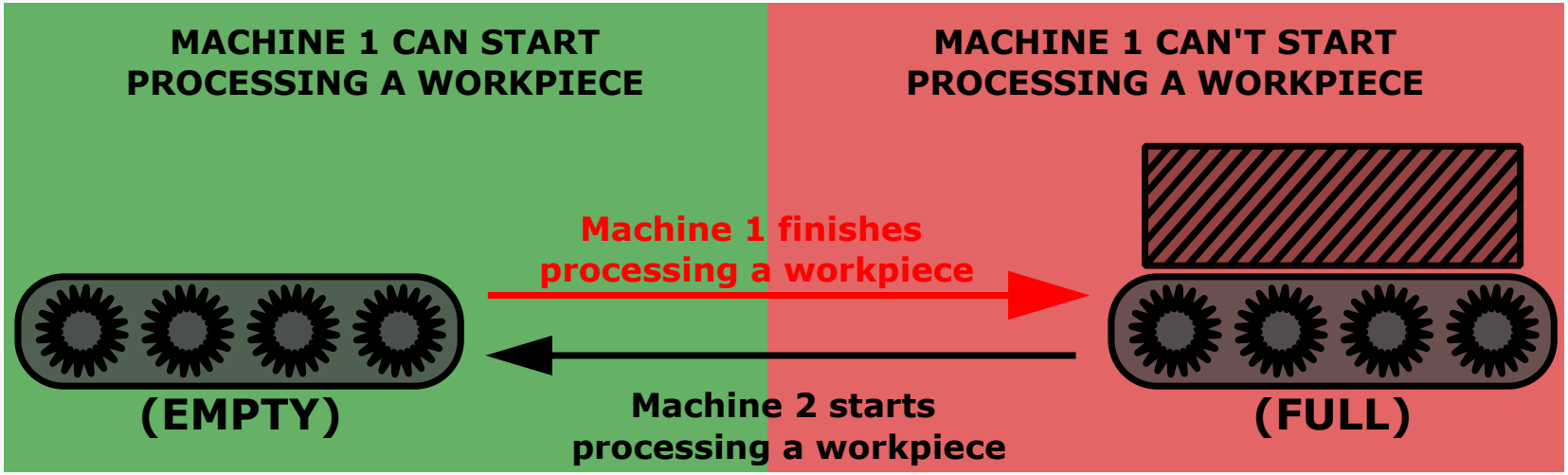


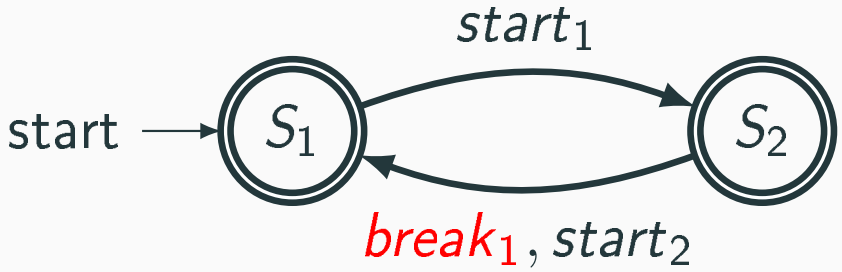


That's it! You got it!

Another alternative version for R_1 - Right or wrong?

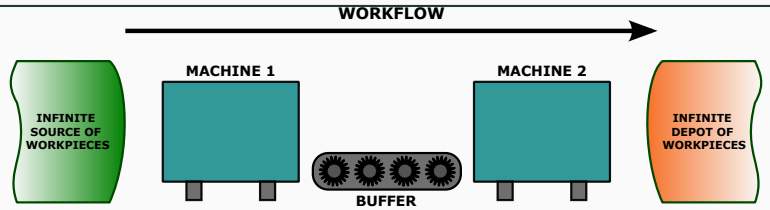
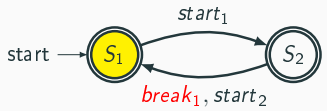
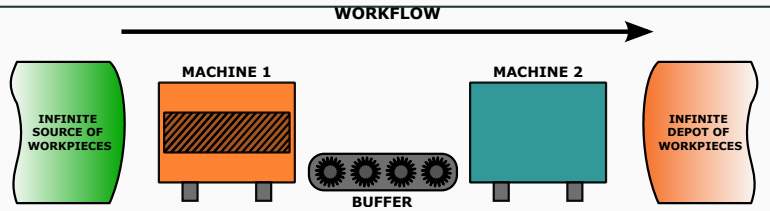
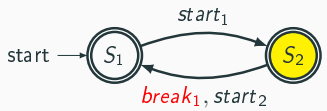
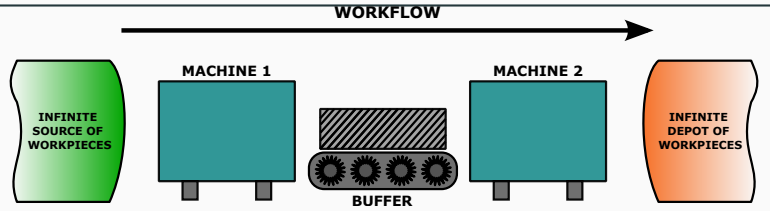
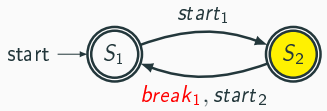
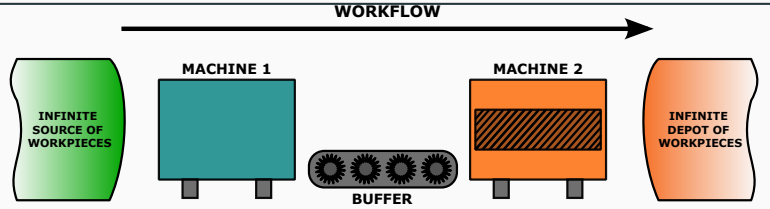
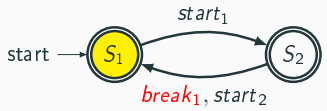
Requirement 1: Machine 1 can start processing a workpiece only if the Buffer is empty



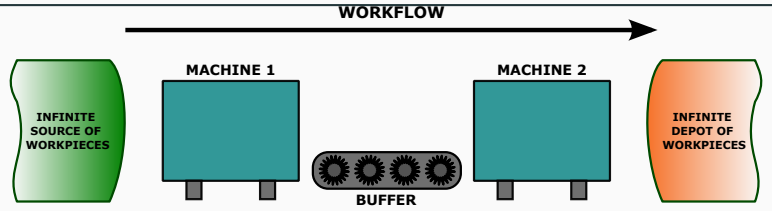
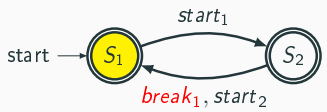
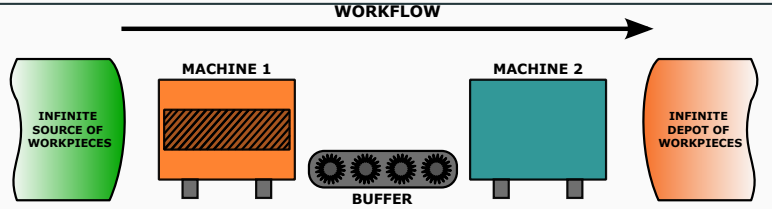
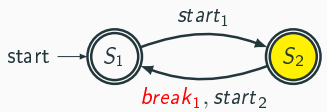
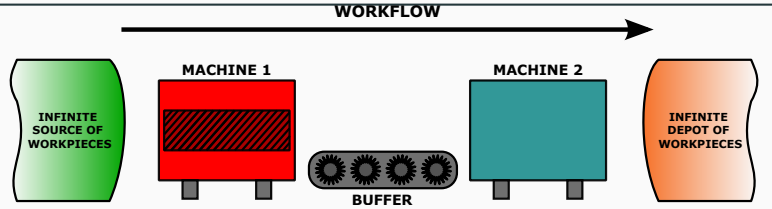
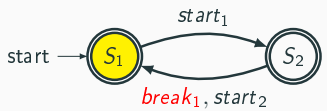
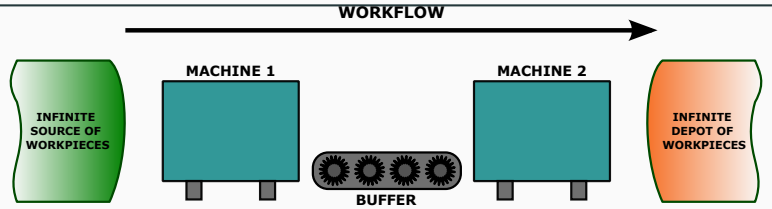
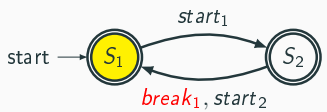


What about this one (no longer related to the buffer automaton)?

Alternative R_1 - Usecase 1

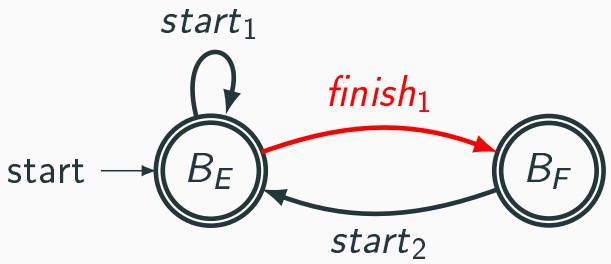
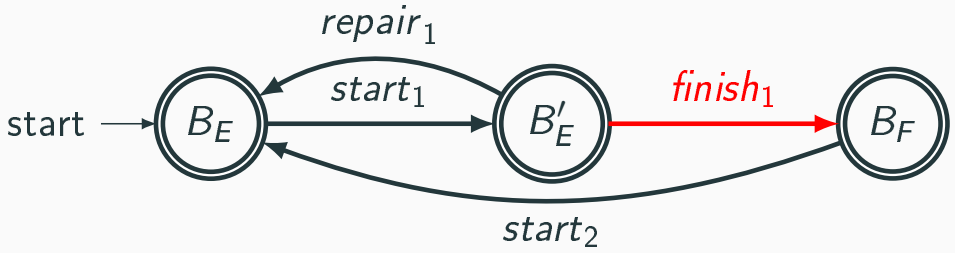
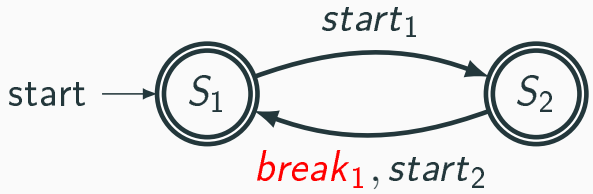
Graphical Representation	Requirement	Description
		Whole system is idle
		M_1 starts processing a workpiece
		M_1 finishes processing the workpiece
		M_2 starts processing the workpiece

Alternative R_1 - Usecase 2

Graphical Representation	Requirement	Description
		Whole system is idle
		M_1 starts processing a workpiece
		M_1 breaks down
		M_1 is repaired and can start again

Correct!

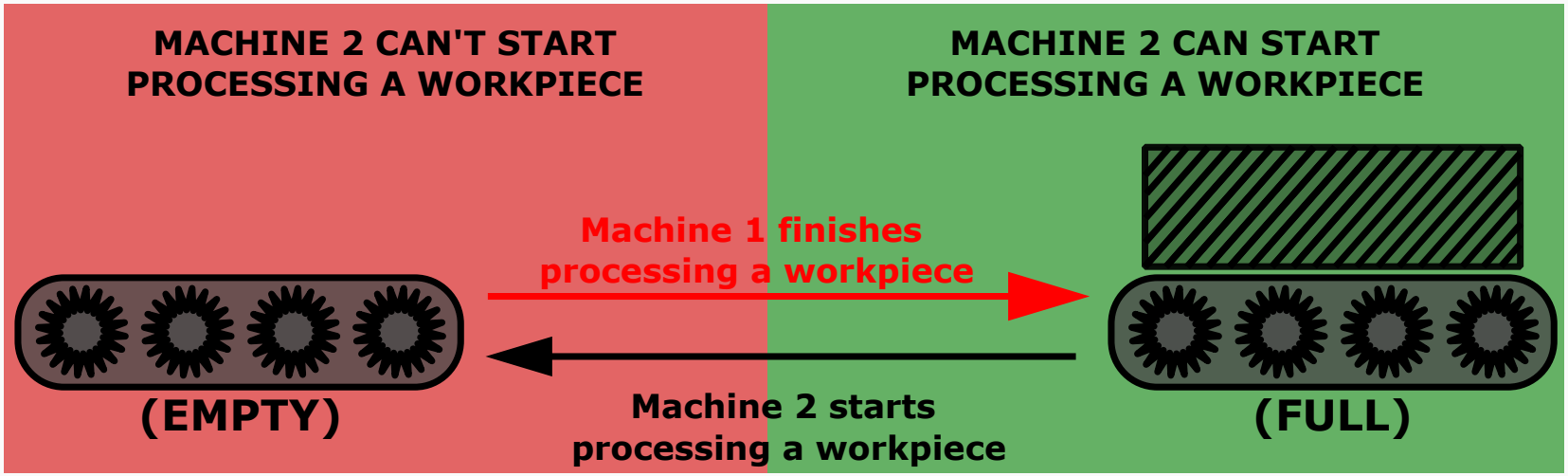
Automata for R_1 - Summary of Equivalent Versions

Version	Automaton	Modeling Intuition
Version 1		**A modified copy of Buffer**
Version 2		**Still a copy of buffer in some sense**
Version 3		**Not from a copy of the buffer**

Homework: check that the effect of each version of R_1 on the plant is the same.

Requirement R_2 - Automaton

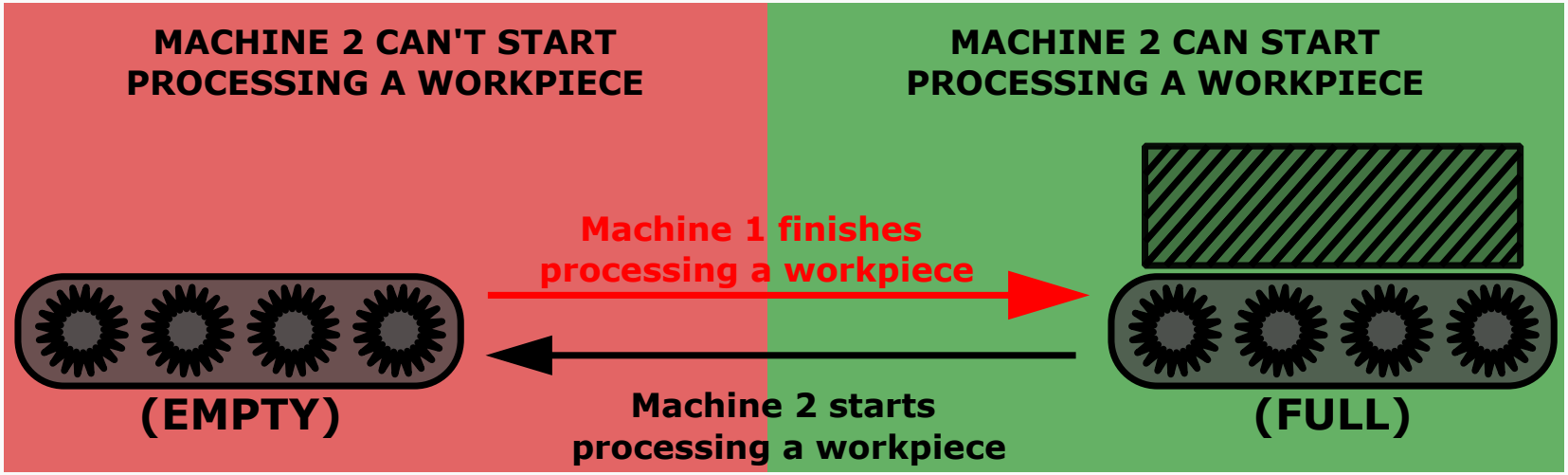
Requirement 2: Machine 2 can start processing a workpiece only if the Buffer is full

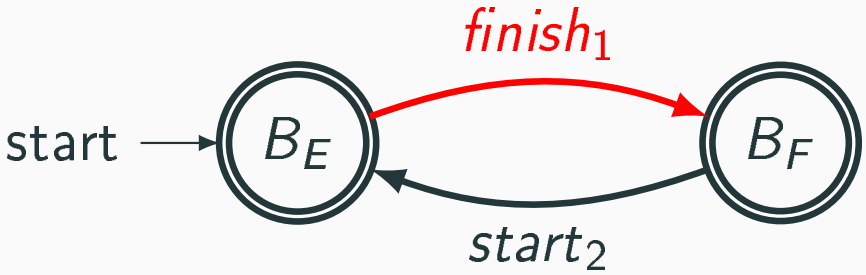


- States?
- Transitions?
- Event controllability?

Requirement R_2 - Essential Desired Behavior

Requirement 2: Machine 2 can start processing a workpiece only if the Buffer is full

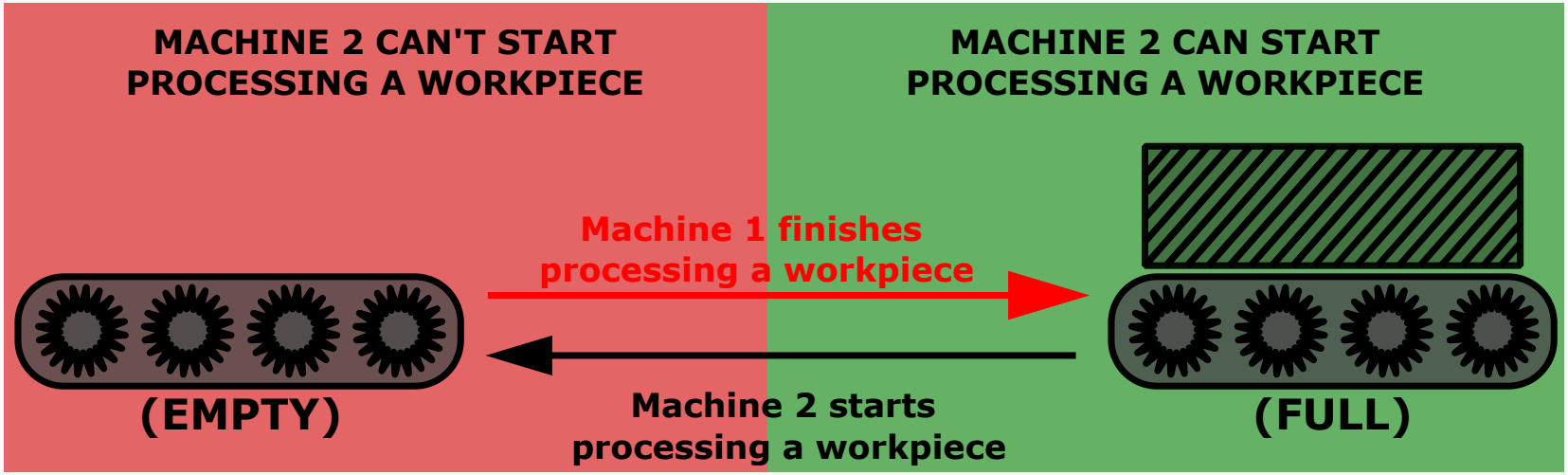




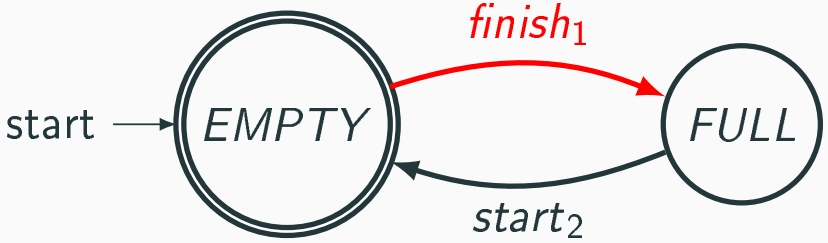
Doesn't it look familiar?

Requirement R_2 - Essential Desired Behavior

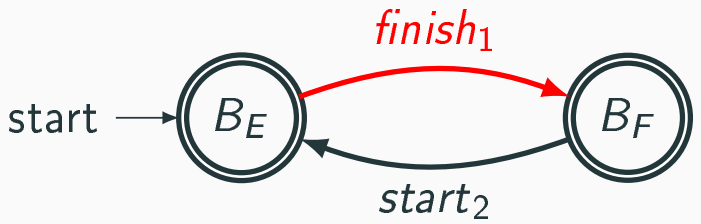
Requirement 2: Machine 2 can start processing a workpiece only if the Buffer is full



Buffer B



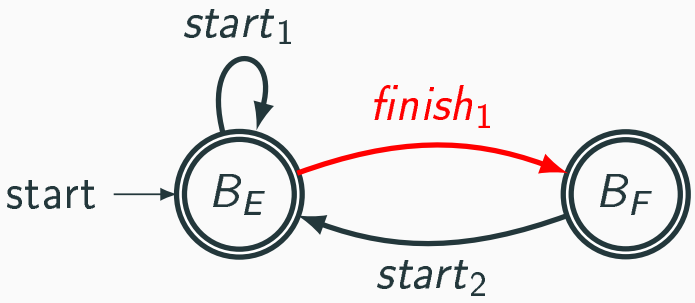
Requirement R_2



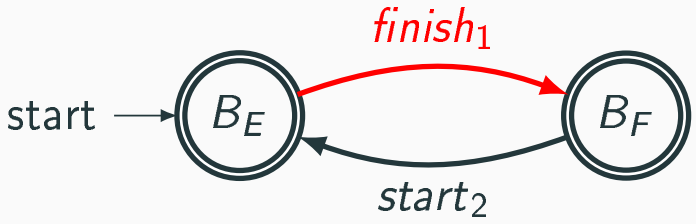
R_2 is already enforced by the plant. Note that $B \| R_2 = B \times R_2 = B$.

Requirement $R_{1,2}$ - Parallel composition point of view

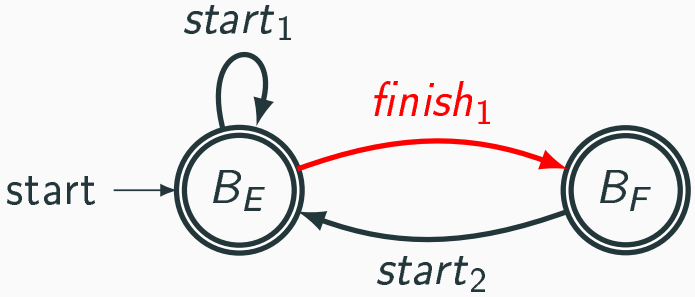
Requirement R_1 (v.1): Machine 1 can start processing a workpiece only if the Buffer is empty



Requirement R_2: Machine 2 can start processing a workpiece only if the Buffer is full

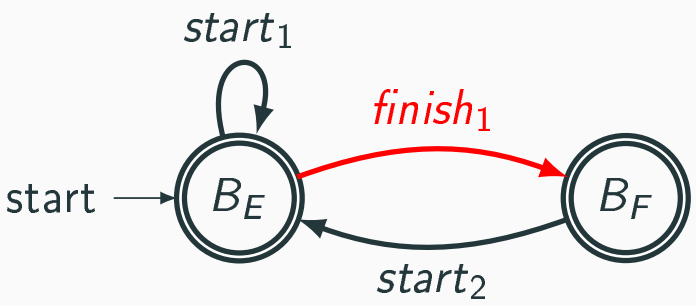


Requirement $R_{1,2} := R_1 \| R_2$

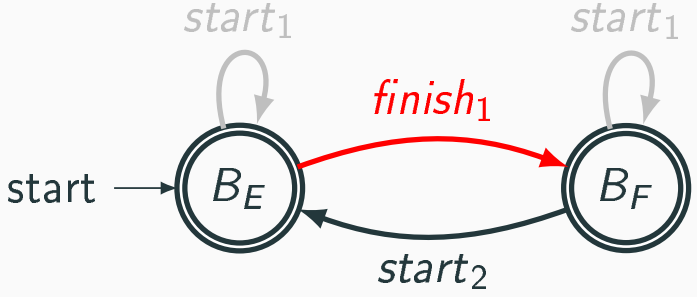


Requirement $R_{1,2}$ - Product point of view

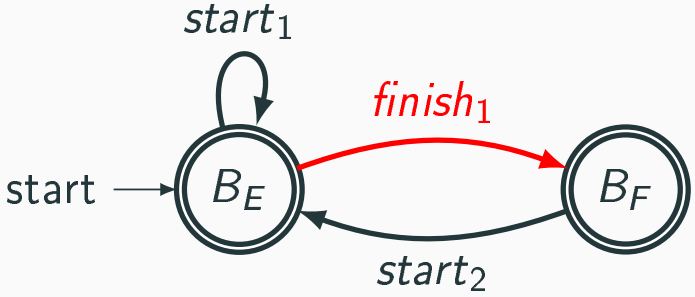
Requirement R_1 (v.1): Machine 1 can start processing a workpiece only if the Buffer is empty



Requirement R_2: Machine 2 can start processing a workpiece only if the Buffer is full

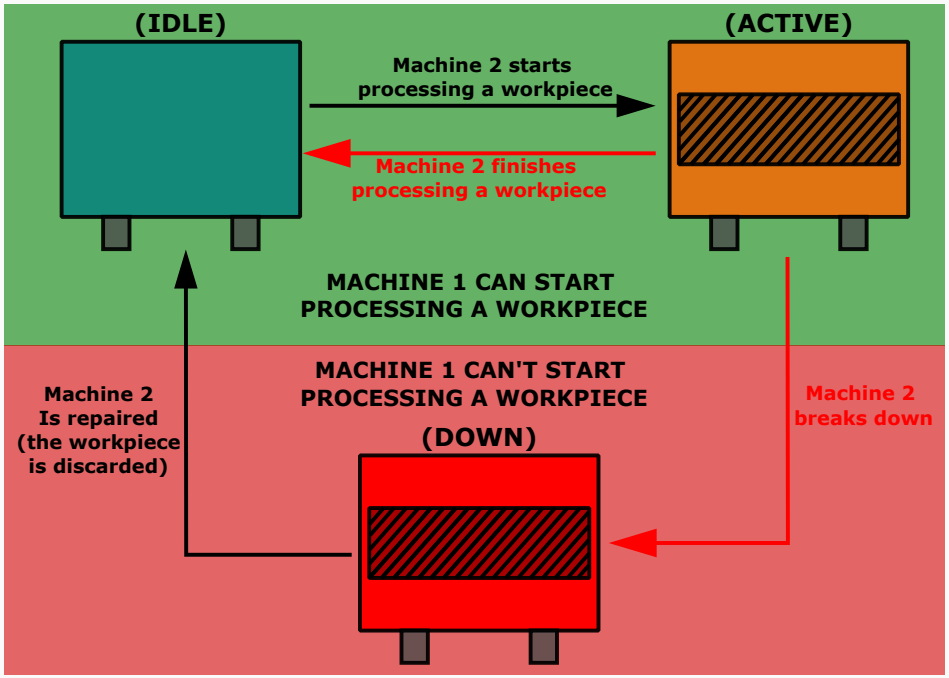


Requirement $R_{1,2} := R_1 \times R_2$



Requirement R_3 - Essential Desired Behavior

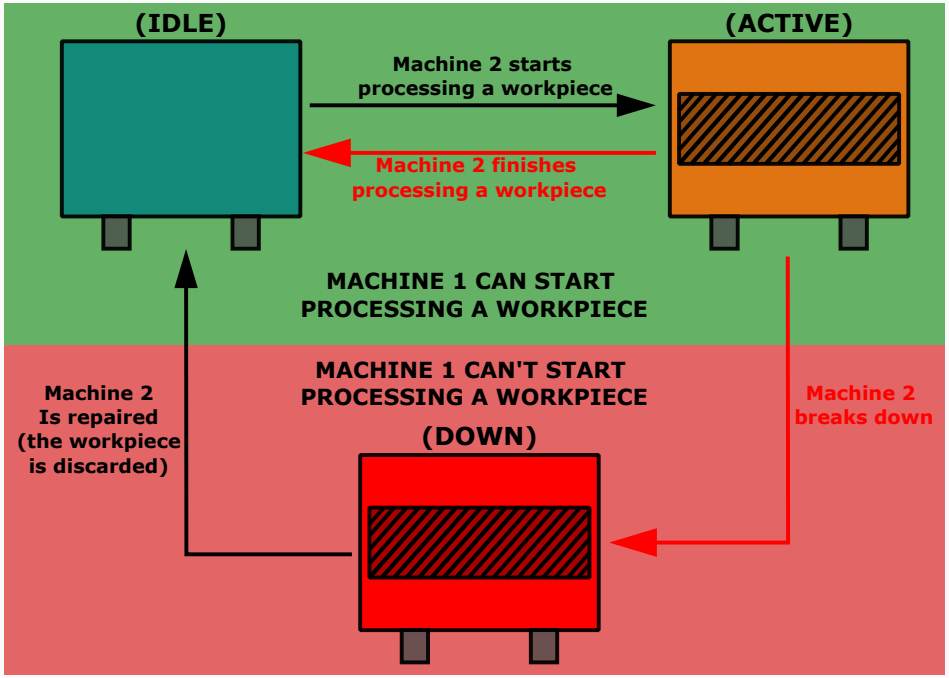
Requirement 3: Machine 1 can't start processing a workpiece if Machine 2 is down.

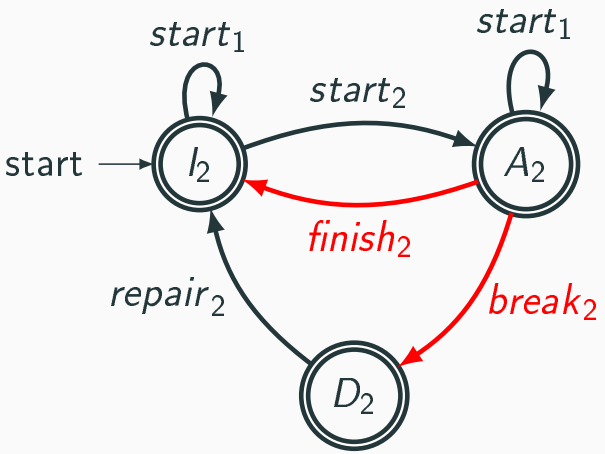


- States?
- Transitions?
- Event controllability?

Requirement R_3 - Attempt 1

Requirement 3: Machine 1 can't start processing a workpiece if Machine 2 is down.



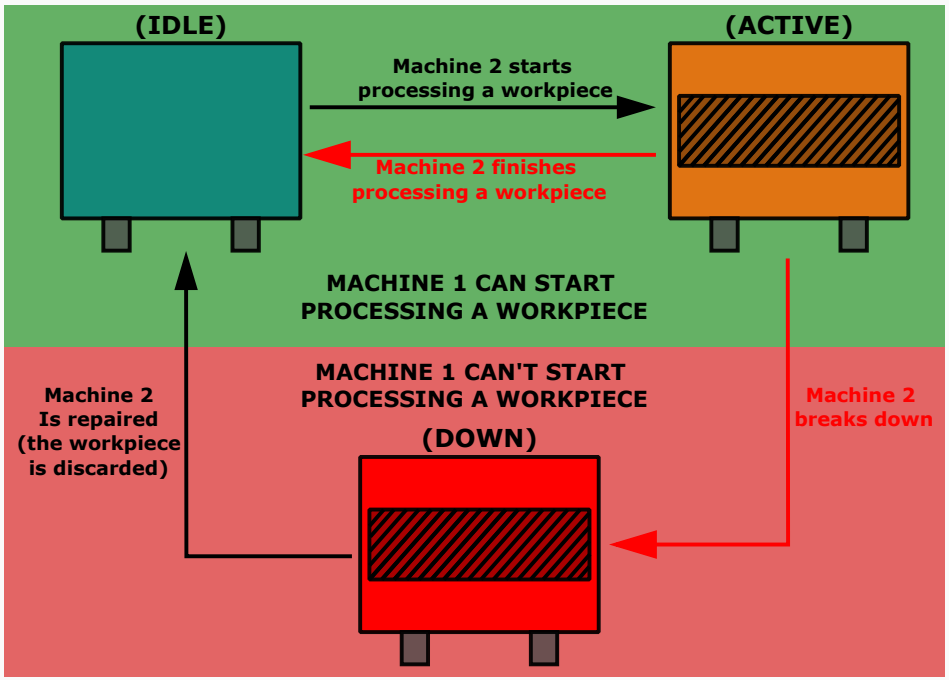


Correct, but maybe not "so essential".

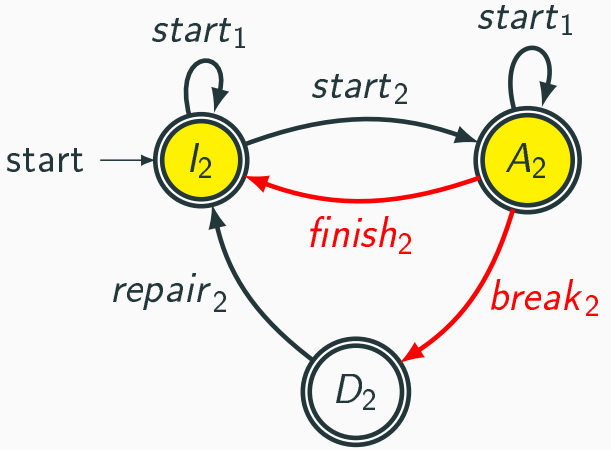
Can we get a smaller automaton?

Requirement R_3 - Attempt 2

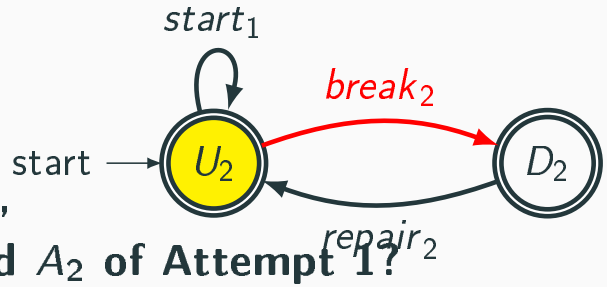
Requirement 3: Machine 1 can't start processing a workpiece if Machine 2 is down.



Requirement R_3 - Attempt 1

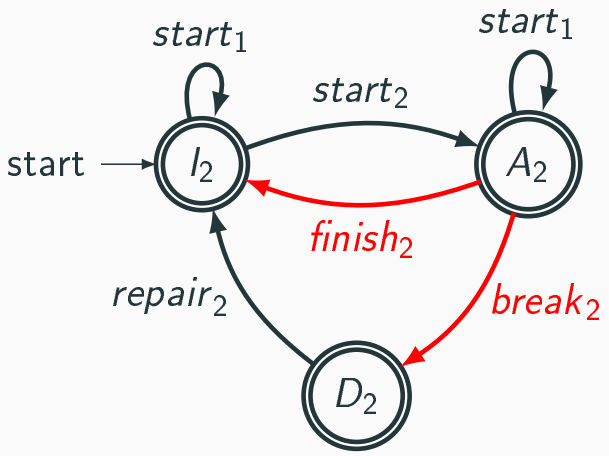
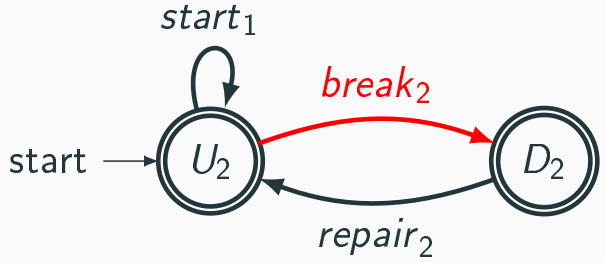


Requirement R_3 - Attempt 2



Note: to capture the essence of the requirement, we do not need $start_2$ and $finish_2$.
Can you now see why we can merge states I_1 and A_2 of Attempt 1?

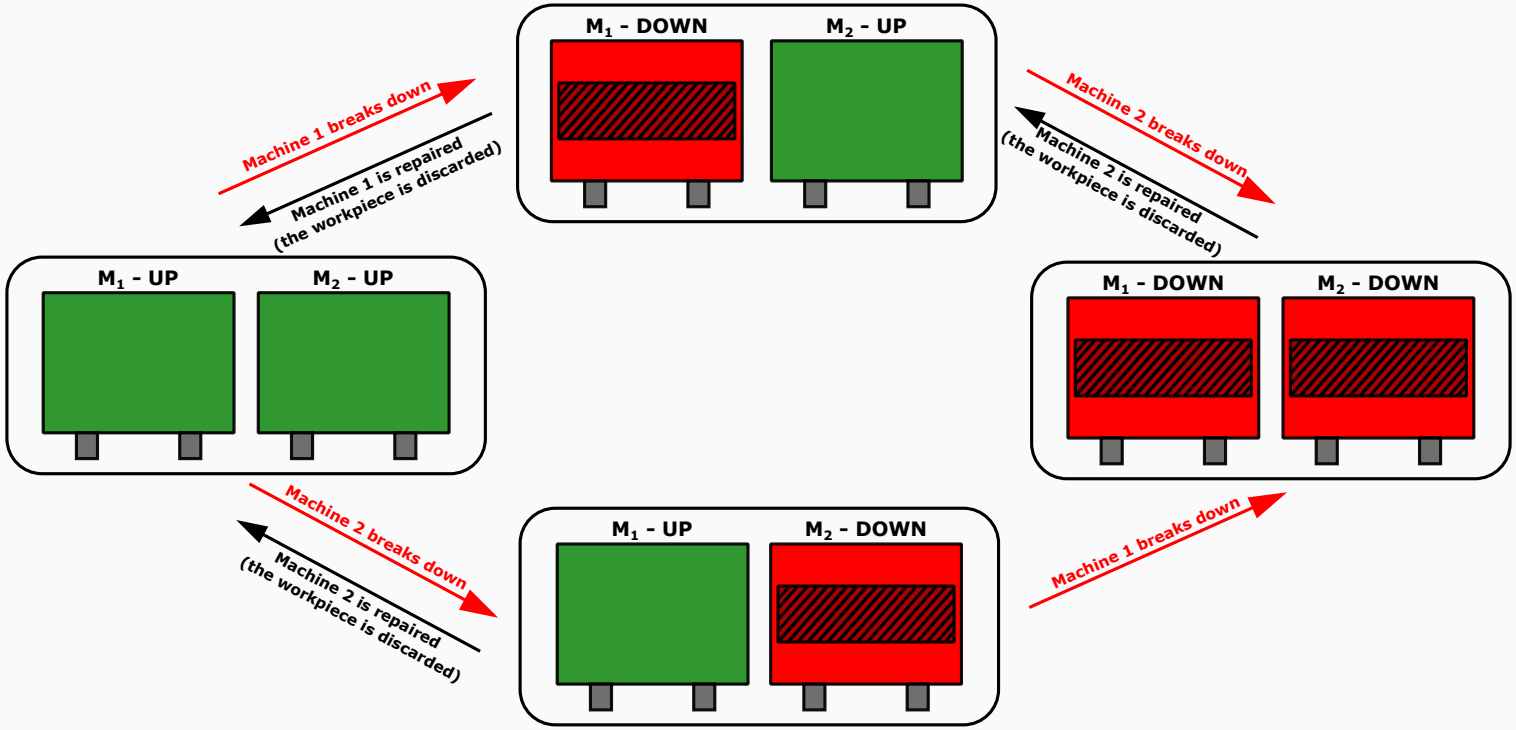
Automata for R_3 - Summary of Equivalent Versions

Version	Automaton	Modeling Intuition
Version 1		**A modified copy of Machine 2**
Version 2		**Still a copy of Machine 2 in some sense**

Homework: check that the effect of each version of R_3 on the plant is the same.

Requirement R_4 - Attempt 1

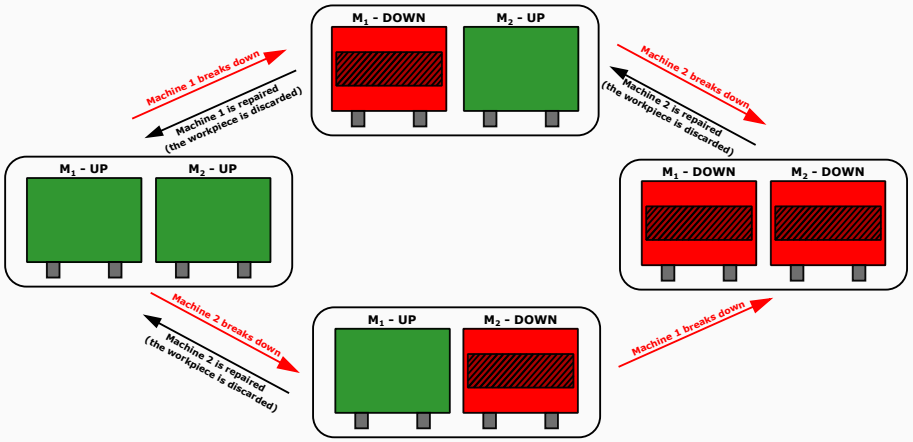
Requirement 4: If both Machines are down, then Machine 2 is repaired before Machine 1.

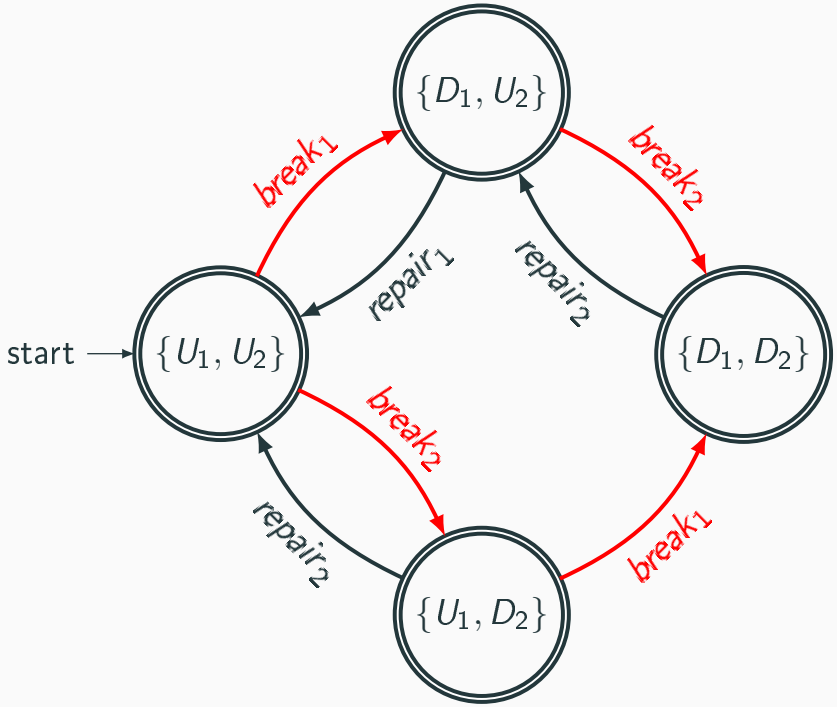


- States?
- Transitions?
- Event controllability?

Requirement R_4 - Attempt 1

Requirement 4: If both Machines are down, then Machine 2 is repaired before Machine 1.



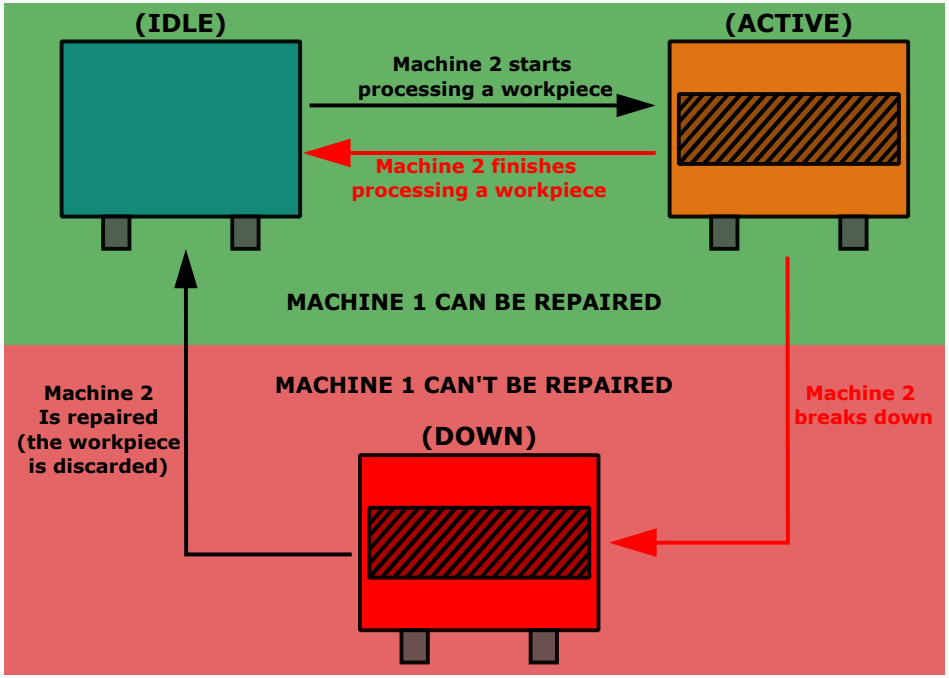


Easy and correct.

Can we improve on the essentiality of the requirement?

Requirement R_4 - Attempt 2 - Desired Behavior

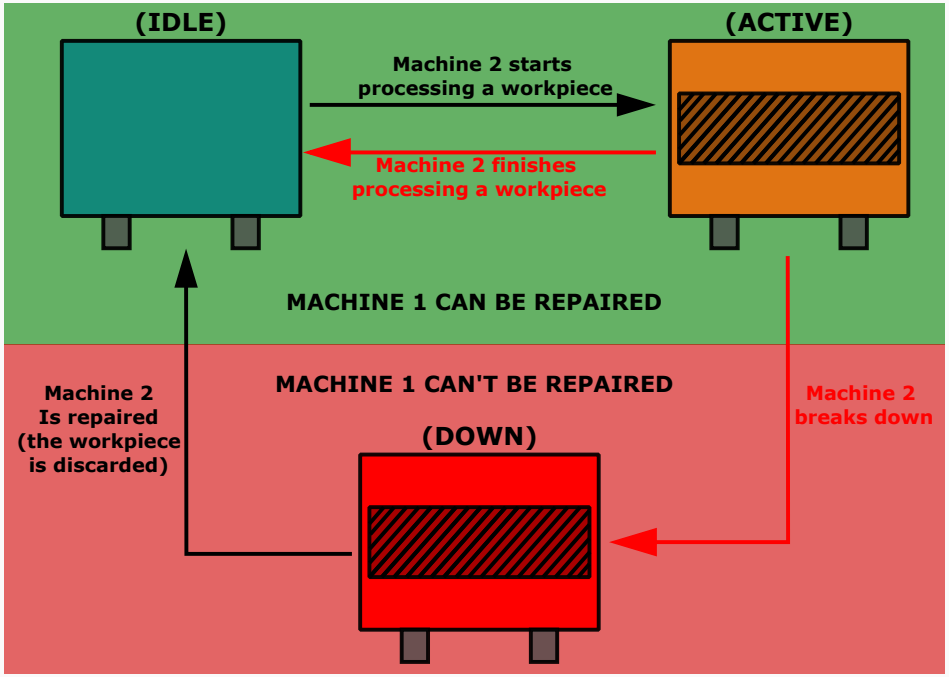
Requirement 4: If both Machines are down, then Machine 2 is repaired before Machine 1.

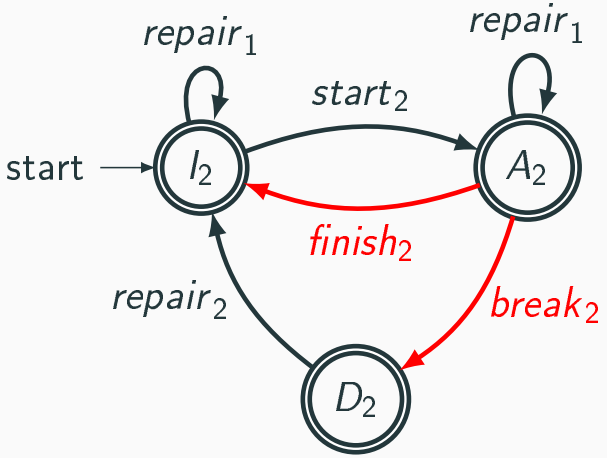


- States?
- Transitions?
- Event controllability?

Requirement R_4 - Attempt 2 - Automaton

Requirement 4: If both Machines are down, then Machine 2 is repaired before Machine 1.





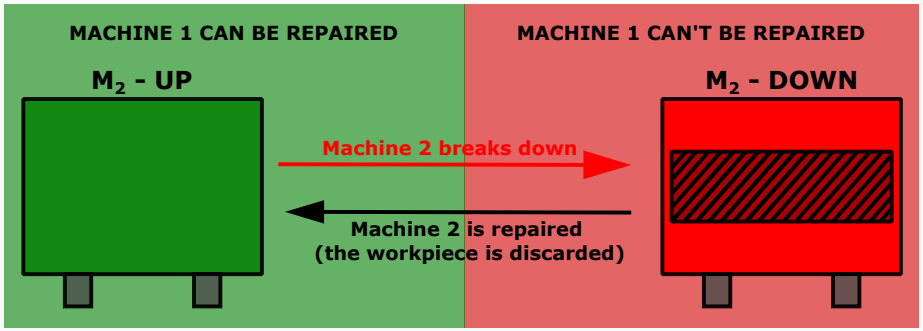
Easy and correct.

Can we improve on the essentiality of the requirement?

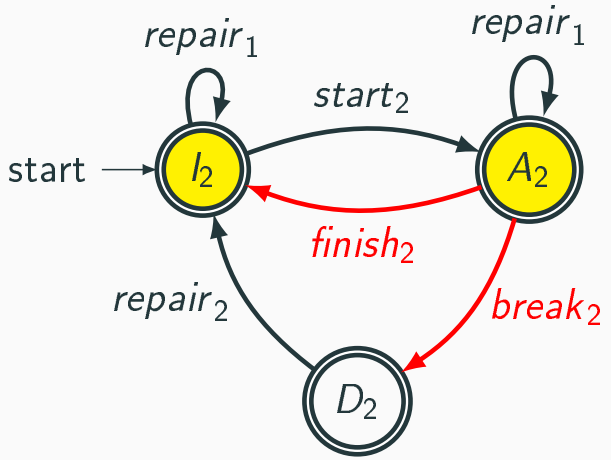
Rationale: When Machine 2 is down if we repair Machine 1 it means that Machine 1 is down as well.

Requirement R_4 - Attempt 3 - Automaton

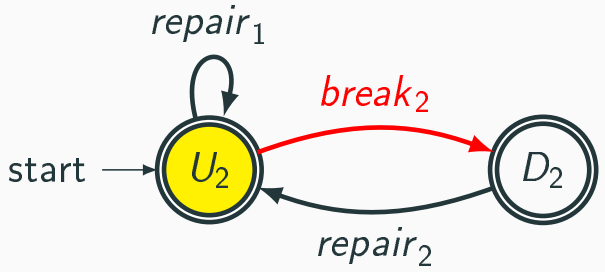
Requirement 4: If both Machines are down, then Machine 2 is repaired before Machine 1.



Requirement R_4 - Attempt 2

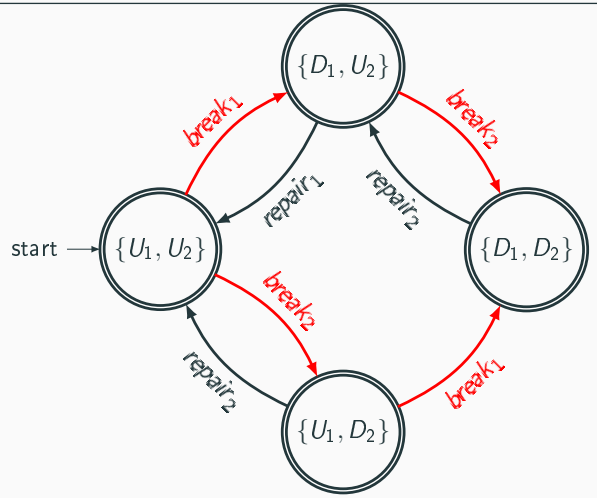
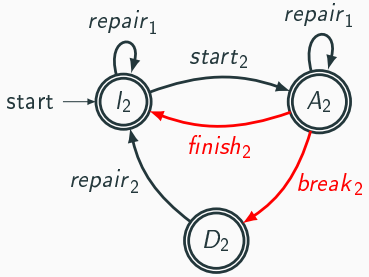
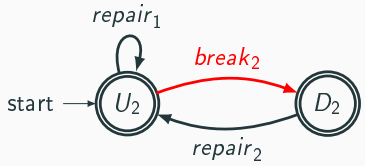


Requirement R_4 - Attempt 3



Recall the concept of
"Machine is UP"
(=Machine is NOT down)

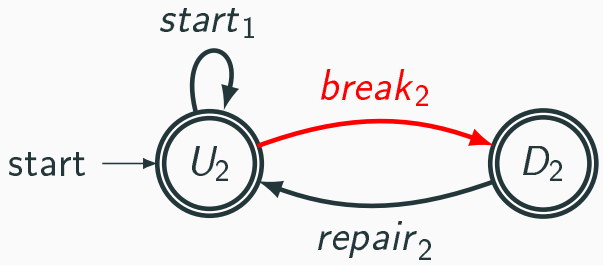
Automata for R_4 - Summary of Equivalent Versions

Version	Automaton	Modeling Intuition
Version 1		A modified copy on a restriction of $M_1 \| M_1$
Version 2		A modified copy of M_2
Version 3		Still a restricted copy of M_2 in some sense

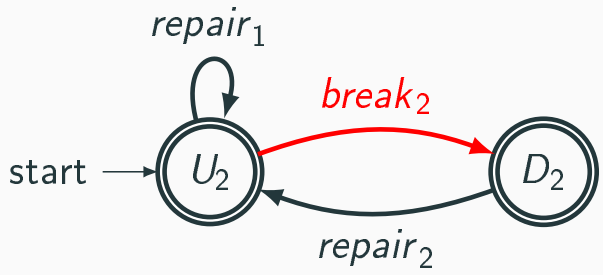
Homework: check that the effect of each version of R_4 on the plant is the same.

Requirement $R_{3,4}$ - Parallel composition point of view

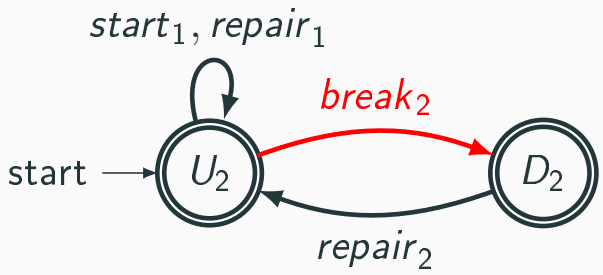
Requirement R_3 (v.2): Machine 1 can't start processing a workpiece if Machine 2 is down.



Requirement R_4 (v.3): If both Machines are down, then Machine 2 is repaired before Machine 1.

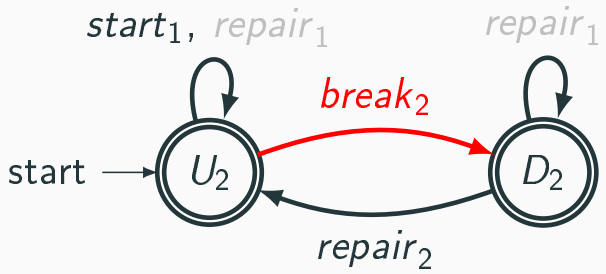


Requirement $R_{3,4} := R_3 \| R_4$

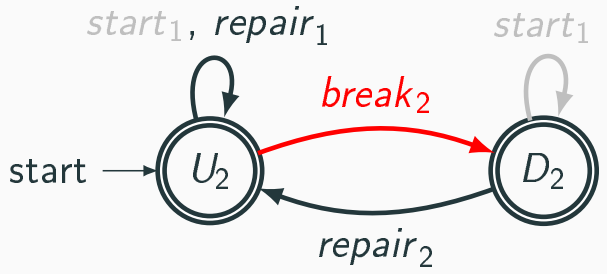
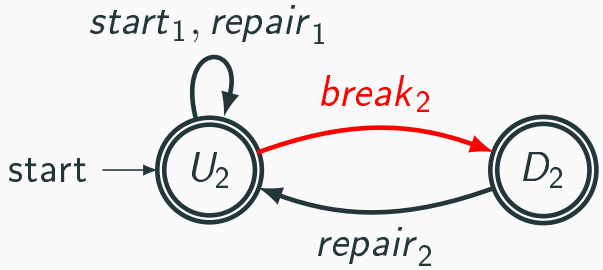


Requirement $R_{3,4}$ - Product composition point of view

Requirement R_3 (v.2): Machine 1 can't start processing a workpiece if Machine 2 is down.



Requirement R_4 (v.3): If both Machines are down, then Machine 2 is repaired before Machine 1.



Requirement $R_{3,4} := R_3 \times R_4$