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DÉVELOPPEMENT DE SYSTÈMES CRITIQUES AVEC LA MÉTHODE EVENT-B

LA VALIDATION D'UN MODÈLE EVENT-B AVEC PROB

3A cursus ingénieurs - Mention Sciences du Logiciel
CentraleSupelec - Université Paris-Saclay - 2024/2025

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OUTLINE

Back to the begin - Back to the outline

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THE PROOF WITH ATELIER-B

- There are two main proof activities in the **Event-B** method :
  1. the proof of consistency used to show that the events of a machine preserve the invariant,
  2. the proof of refinement used to show that one machine is a valid refinement of another.

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- In some cases, the most complex **POs** are not proved automatically and *must be proved interactively*.

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HISTORY OF FORMAL VERIFICATION METHODS

Before…

- Software code was sequential
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- Theorem provers $\longrightarrow$ partial/total correctness
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After 80's

- Software is concurrent and reactive
- Properties are expressed in Temporal Logic
- Solving accurate properties like safety, liveness, fairness…
- Push-Button $\longrightarrow$ decidable (e.g. Model Checking)

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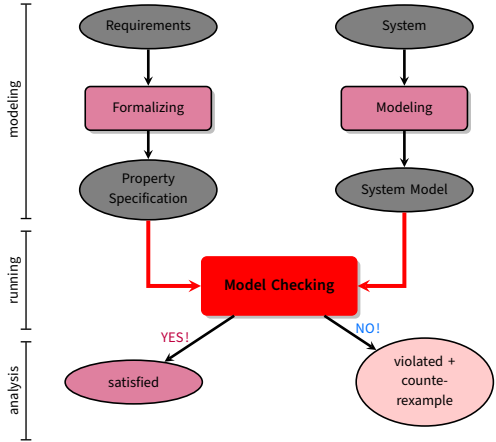
PRINCIPLE OF MODEL-CHECKING



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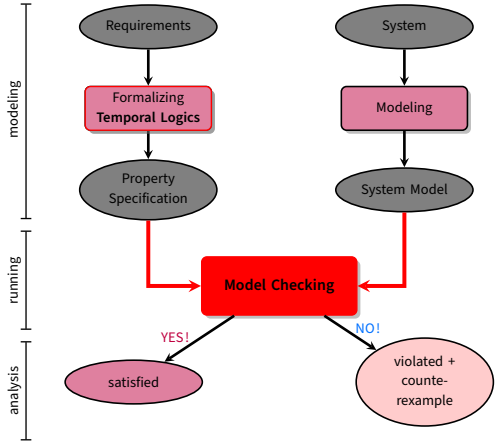

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PROPOSITIONAL LOGIC

$$\phi \quad ::= \quad true \quad | \quad a \quad | \quad \phi \quad \wedge \quad \phi \quad | \quad \neg \phi$$

where $a \in AP$

PROPOSITIONAL LINEAR TEMPORAL LOGIC

$$\phi \quad ::= \quad true \quad | \quad a \quad | \quad \phi \quad \wedge \quad \phi \quad | \quad \neg \phi \quad | \quad \bigcirc \phi$$

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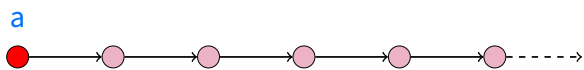
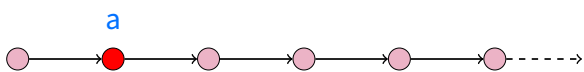
$\bigcirc$
(next)

$\sigma \models a$



$\sigma \models \bigcirc a$



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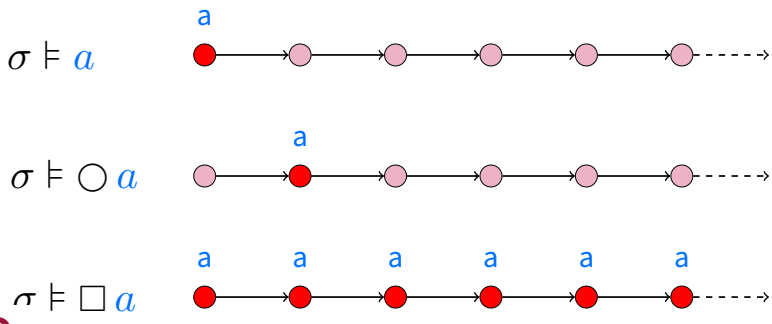
$\bigcirc$ (next) $\Box$ (always)



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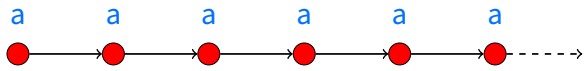
LTL : DERIVED TEMPORAL OPERATORS

$\Box\phi$

(always)

$\sigma \models \Box\, a$

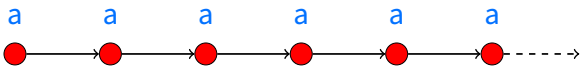


LTL : DERIVED TEMPORAL OPERATORS

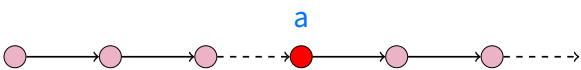
$\Box\phi$ (always)

$\Diamond\phi \equiv \neg\Box\neg\phi$ (eventually)

$\sigma \models \Box\, a$



$\sigma \models \Diamond\, a$



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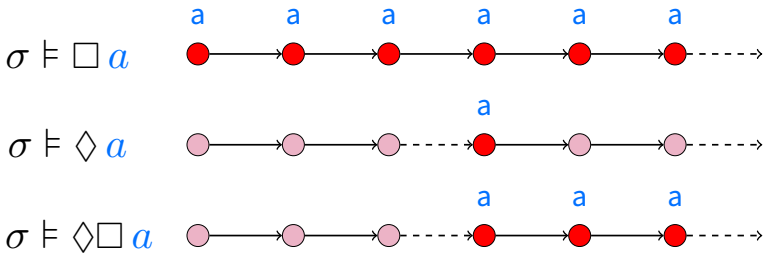
LTL : DERIVED TEMPORAL OPERATORS

$\Box\phi$ (always) $\Diamond\phi \equiv \neg\Box\neg\phi$ (eventually) $\Diamond\Box\phi$ (persistence)



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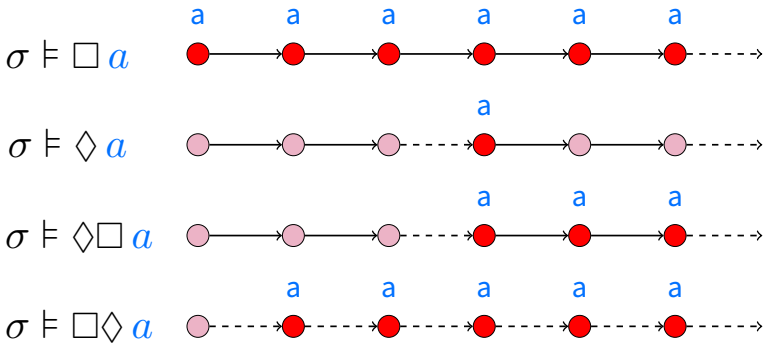
LTL : DERIVED TEMPORAL OPERATORS

$\Box\phi$ (always)

$\Diamond\phi \equiv \neg\Box\neg\phi$ (eventually)

$\Diamond\Box\phi$ (persistence)

$\Box\Diamond\phi \equiv \neg\Diamond\Box\neg\phi$ (infinitely many)



$\{\, i \mid a \in \sigma(i) \,\}$ is infinite

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EXAMPLE OF TEMPORAL PROPERTIES

- **Safety** :
  - mutual exclusion : $\Box\neg(crit_1 \wedge crit_2)$
  - elevator : $\Box(moving \Rightarrow doors_{closed})$
  - traffic light : $\Box(yellow \Rightarrow \bigcirc red)$

EXAMPLE OF TEMPORAL PROPERTIES

- **Safety** :
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  - elevator : $\Box(moving \Rightarrow doors_{closed})$
  - traffic light : $\Box(yellow \Rightarrow \bigcirc red)$
- **Liveness** :
  - progress : $\Diamond\, progress$
  - response : $\Box(try\_to\_send \Rightarrow \Diamond delivered)$
  - termination : $\Diamond\Box\, terminated$

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EXAMPLE OF TEMPORAL PROPERTIES

- **Safety** : nuclear plant
  - cooling : $\Box\neg(temp_{high} \wedge cooling_{low})$
  - alarm : $\Box(temp_{high} \Rightarrow alarm)$
  - saving : $\Box(temp_{high} \Rightarrow \bigcirc react_{low})$

EXAMPLE OF TEMPORAL PROPERTIES

- **Safety** : nuclear plant
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- **Liveness** : nuclear plant
  - reactivity : $\Box\Diamond\, react_{high}$
  - temperature : $\Box(react_{low} \Rightarrow \Diamond temp_{low})$

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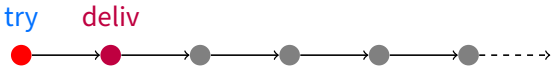
LTL : UNTIL OPERATOR

$$\phi \quad ::= \quad true \quad | \quad a \quad | \quad \phi \quad \wedge \quad \phi \quad | \quad \neg \phi \quad | \quad \bigcirc \phi \quad | \quad \Box \phi$$

$try \Rightarrow \bigcirc deliv$



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LTL : UNTIL OPERATOR

$$\phi \quad ::= \quad true \mid a \mid \phi \wedge \phi \mid \neg\phi \mid \bigcirc\phi \mid \Box\phi \mid \phi \bigcup \phi$$

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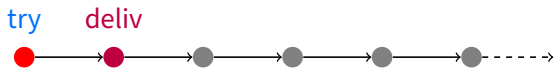

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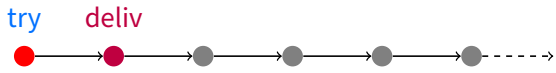

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$$\Diamond\,\phi \;\equiv\; \textbf{true} \;\cup\; \phi$$

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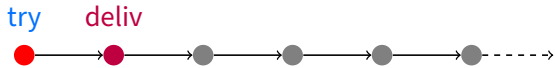

$try \Rightarrow \Diamond deliv$

$try \bigcup deliv$

$\Diamond \phi \equiv$ **true** $\bigcup \phi$ and $\Box \phi \equiv \neg \Diamond \neg \phi$

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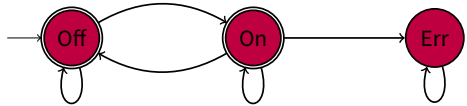
PROPERTIES OF A TRACE



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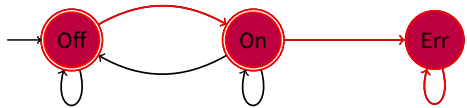
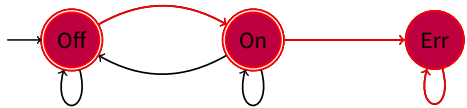


have a path $\pi = Off\, On\, Err\, Err\, Err \ldots = Off\, On\, Err^{\omega}$

- $\pi \models Off$

PROPERTIES OF A TRACE



have a path $\pi = Off\,On\,Err\,Err\,Err\,... = Off\,On\,Err^{\omega}$

- $\pi \models Off$, but $\pi \not\models On$

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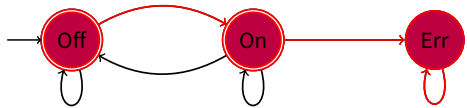

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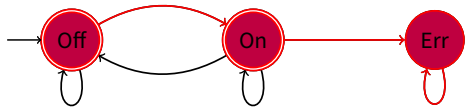

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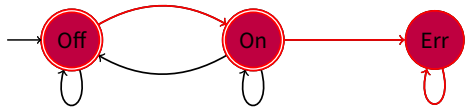

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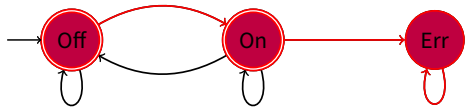

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- $\pi \models (Off \vee On) \cup Err$

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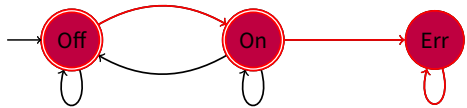

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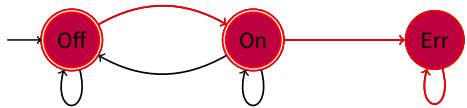
- $\pi \models \Box(Err \Rightarrow \bigcirc Err)$

PROPERTIES OF A TRACE



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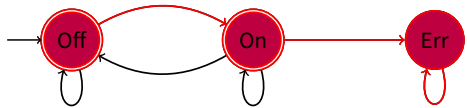

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- $\pi \models \Diamond\Box Err$ $(persistence)$

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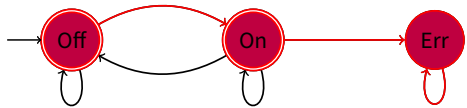

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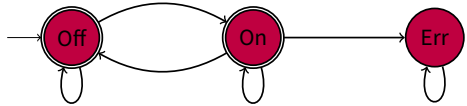
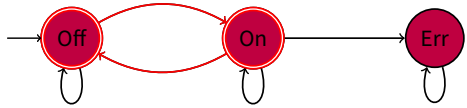


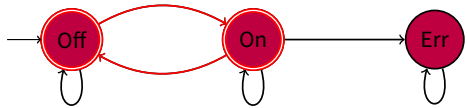
PROPERTIES OF A TRACE



have a path $\pi = Off\,On\,Off\,On\,Off\,... = (Off\,On)^{\omega}$

- $\pi \overset{?}{\models} (Off \vee On) \cup Err$

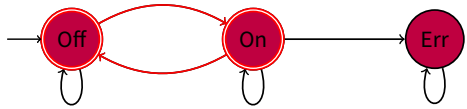
PROPERTIES OF A TRACE



have a path $\pi = Off On Off On Off ... = (Off On)^{\omega}$

- $\pi \not\models (Off \vee On) \cup Err$

PROPERTIES OF A TRACE



have a path $\pi = Off\,On\,Off\,On\,Off\ldots = (Off\,On)^{\omega}$

- $\pi \not\models (Off \vee On) \cup Err$
- $\pi \overset{?}{\models} \Diamond Err \Rightarrow ((Off \vee On) \cup Err)$

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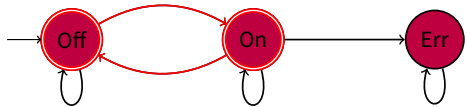
PROPERTIES OF A TRACE



have a path $\pi = Off\,On\,Off\,On\,Off... = (Off\,On)^{\omega}$

- $\pi \not\models (Off \vee On) \cup Err$
- $\pi \models \Diamond Err \Rightarrow ((Off \vee On) \cup Err)$ as $\pi \not\models \Diamond Err$

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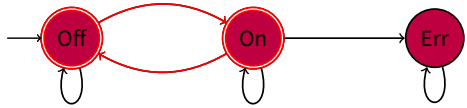
PROPERTIES OF A TRACE



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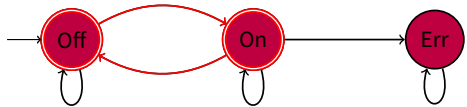

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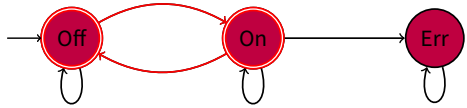

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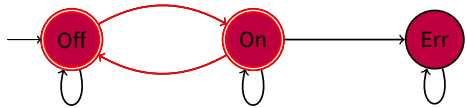

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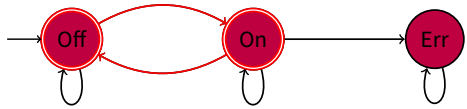

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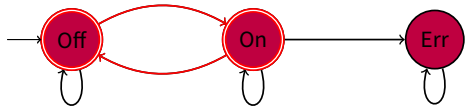

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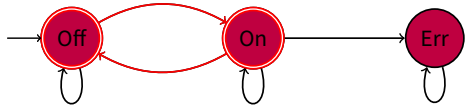

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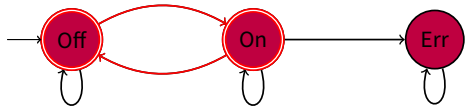

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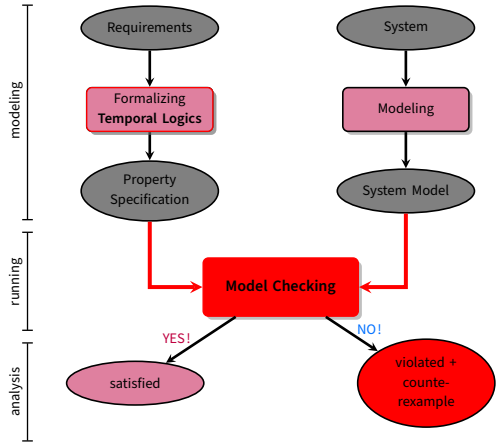
SYSTEM MODELING



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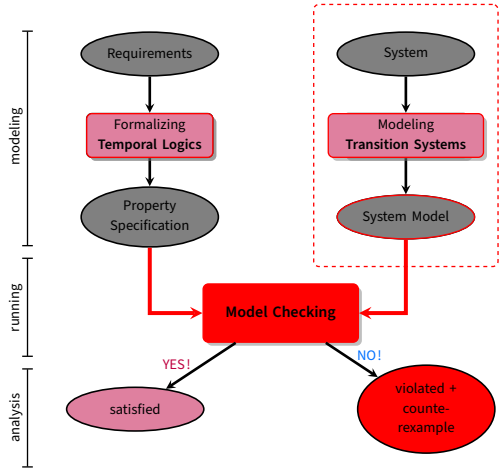

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TRANSITION SYSTEMS

- model to describe the behaviour of systems
- **digraphs** where nodes represent states, and edges represent transitions
- states
  - the current colour of a traffic light : red, green, orange.
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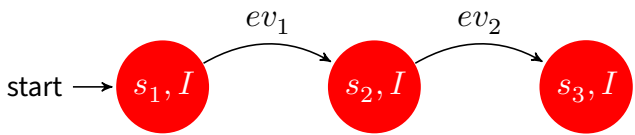
  - transitions (initialisation and events) to update the state (substitutions)



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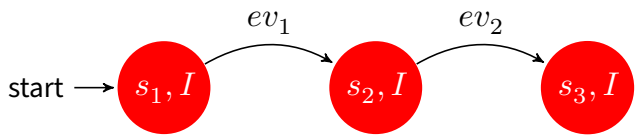
THE REFINEMENT OF AN EVENT-B MODEL



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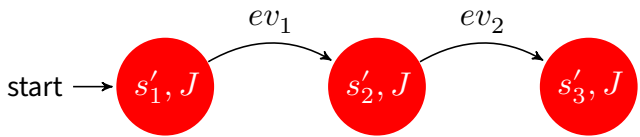

Data refinement (states)

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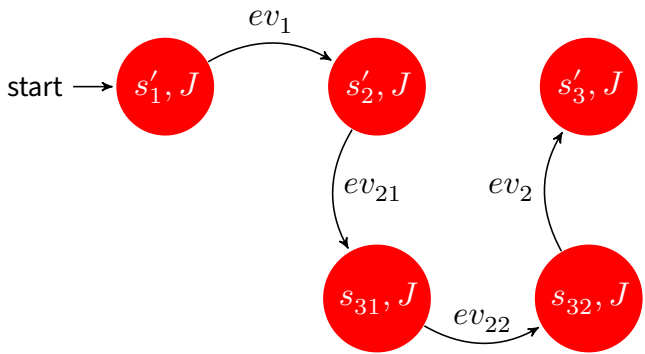
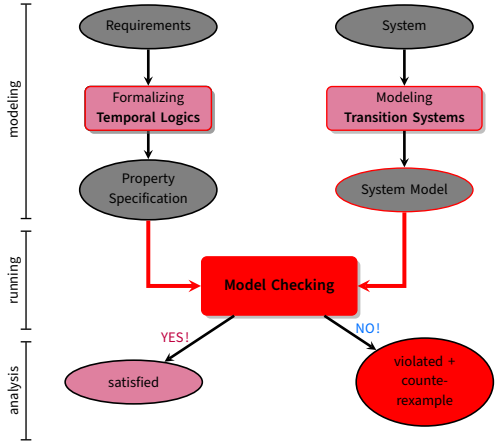


Behavior refinement (events)

PROPERTY SPECIFICATION



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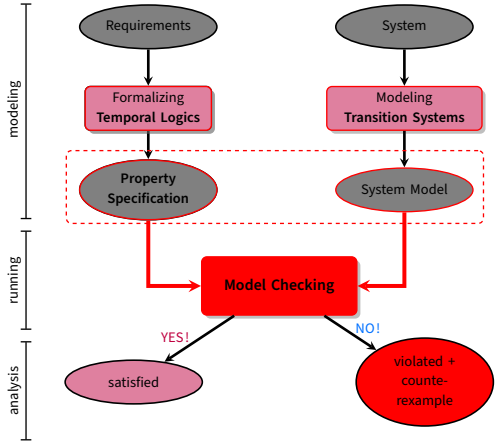

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- Safety properties are complemented by **Liveness properties**
  - that require some progress
  - that assert : "something good" will happen eventually
  - e.g. Eventually : $\Diamond\, crit_1 \wedge \Diamond\, crit_2$

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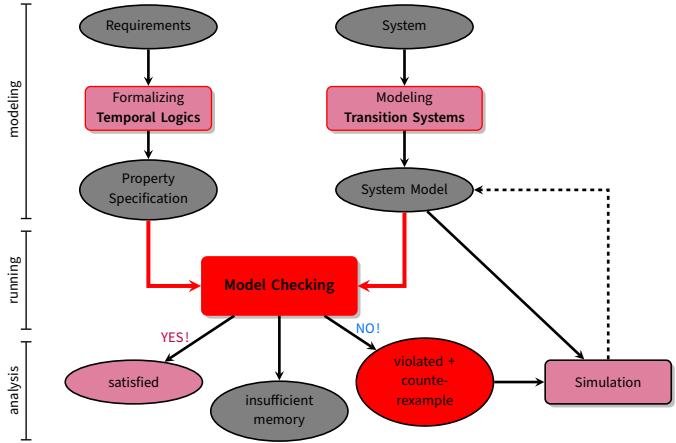
MODEL CHECKING PROCESS



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3. **Analysis phase** (3 cases)
   - property satisfied : check next property (if any)
   - property violated :
     - analyze generated counterexample by simulation
     - modify the model and repeat the entire procedure
   - out of memory : try to reduce the model (abstraction) and try again

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doing things right $\not\Rightarrow$ doing the right thing

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OUTLINE

Back to the begin - Back to the outline

THE PROB
ANIMATOR AND MODEL CHECKER

ProB Main Page

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- Animation features are useful for infinite state machines, not for verification, but for debugging and testing.

ProB Main Page

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  - ➠ allows ProB to browse through the reachable states of the machine.
- The **ProB plugin** graphically displays a counterexample when it discovers a property violation.

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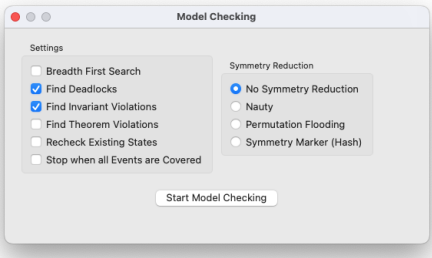
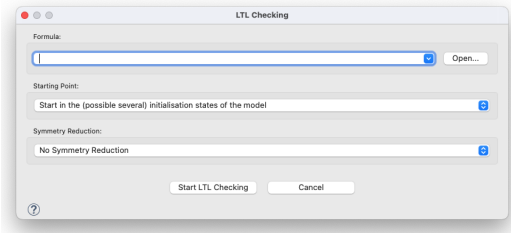
THE PROB PLUGIN





- Tutorial Rodin First Step
- Tutorial First Model Checking
- LTL Model Checking

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- As the interactive proof process can be quite long, the **ProB plugin** can be used as a complement to the interactive proof.
- Some errors will be discovered sooner and designers will waste less effort proving incorrect POs.

THANK YOU

Back to the begin - Back to the outline