MODEL CHECKING

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BASIC INGREDIENTS

- **a language to model the system**
  - -> *formal semantics*
  - -> *many options, e.g.*
    Petri nets
- **a language to specify model properties**
  - -> *temporal Logics,*
  - -> *several options, e.g.*
    Computational Tree Logic (CTL)
- **an analysis approach to check a model against its properties**
  - -> *model checking,*
  - -> *various approaches (algorithms + data structures), e.g.*
    using reachability graph (RG)
    = labelled state transition system (STS) = Kripke structure
    ≈ Continuous Time Markov Chain (CTMC)

- **ACM Turing Award = Nobel Prize of computing**
  goes to Model Checking Pioneers
  Edmund M. Clarke, E. Allen Emerson and Joseph Sifakis
  -> *"For [their roles] in developing Model Checking into a highly effective verificatio technology, widely adopted in the hardware and software industries."*

2007

TEMPORAL LOGICS,

CTL -

A CRASH COURS

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MOTIVATION (1)

- GENERAL PROPERTIES (REQUIREMENTS)

  -> *must be valid for any system, independently of its special functionality*

  -> *boundedness*
  -> *liveness*
  -> *reversibility*
  . . .

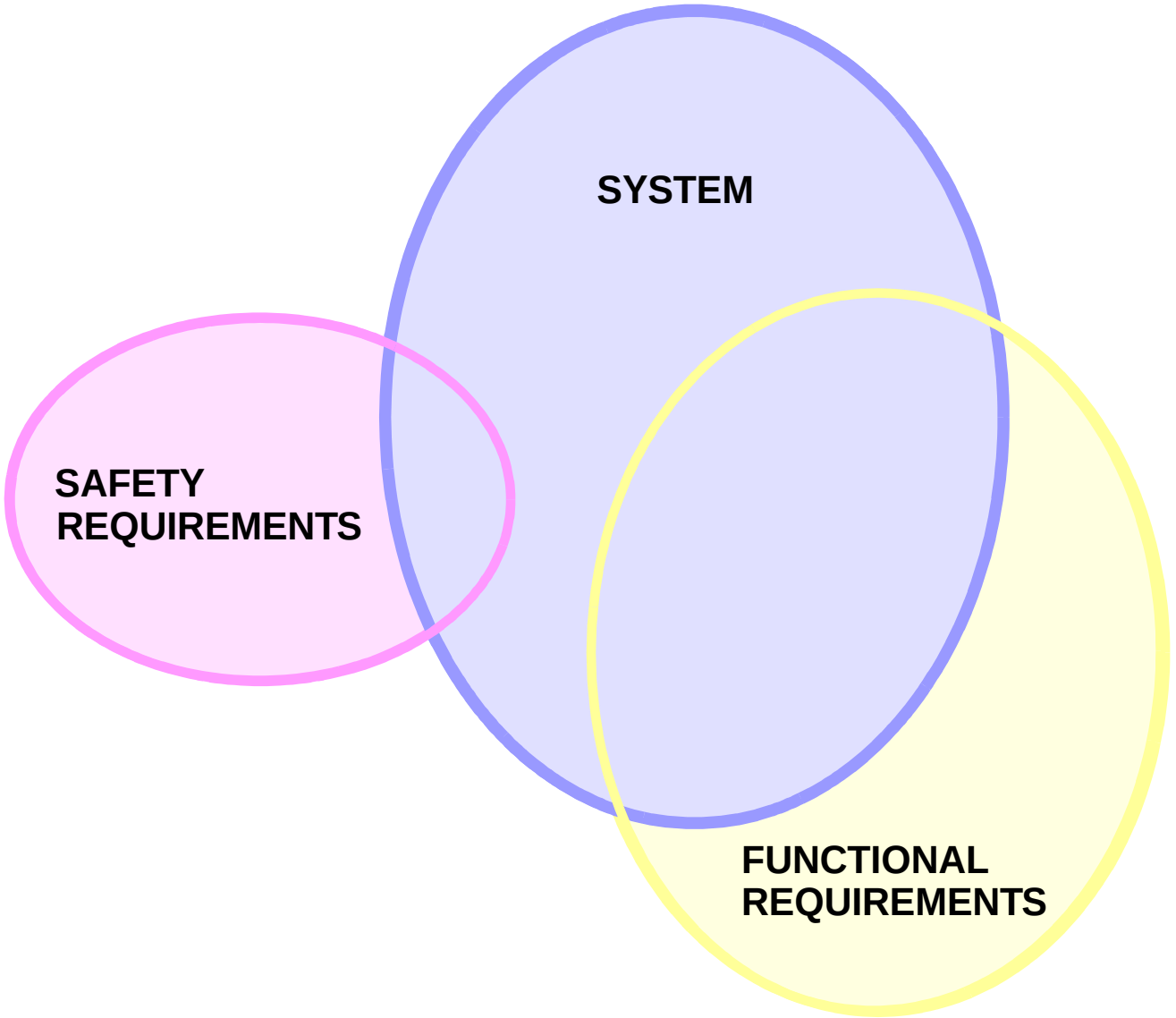
- SPECIAL PROPERTIES (REQUIREMENTS)

  -> *reflect the special functionality*

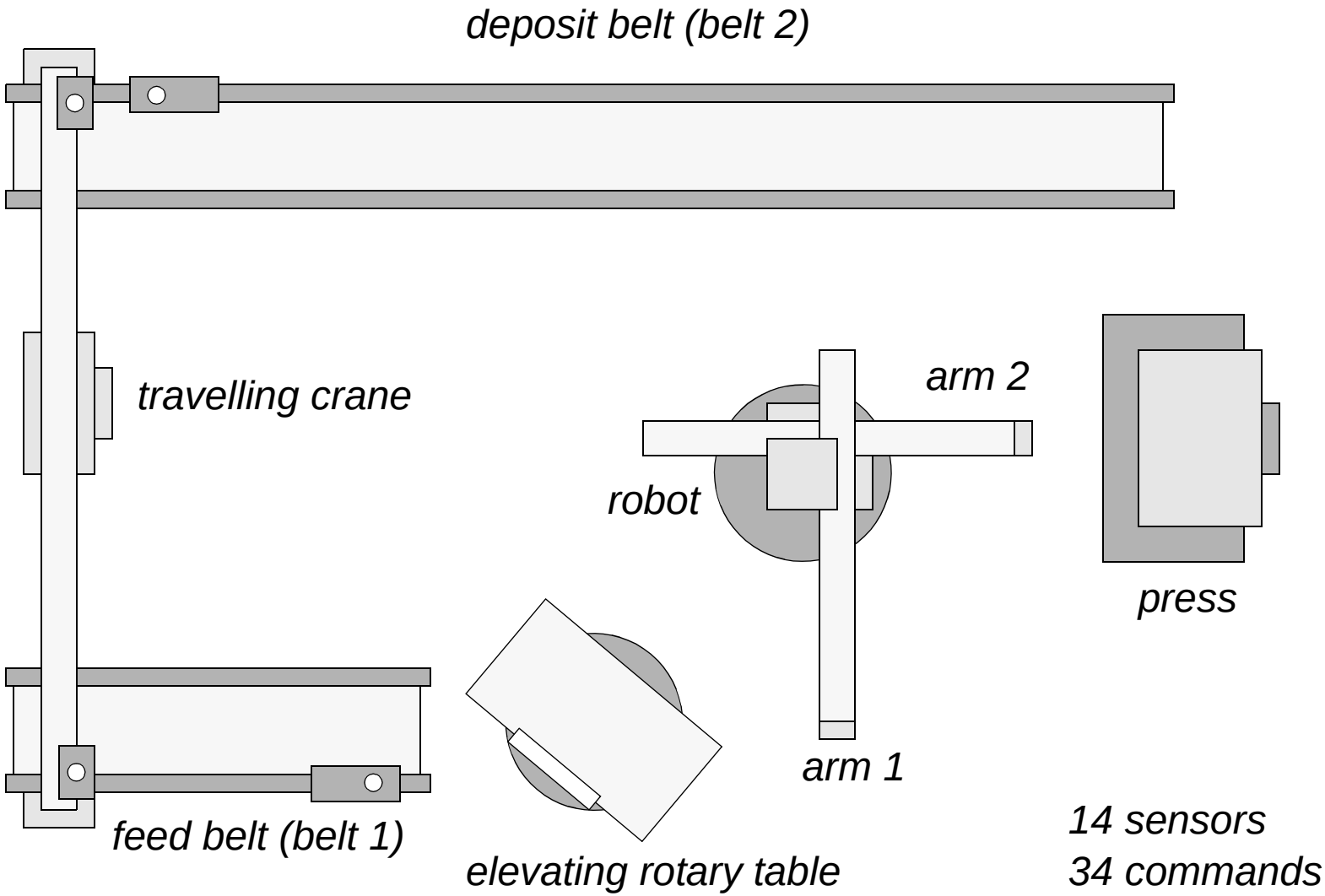
  -> *(i) insights into system behaviour*
  -> *(c) consistency properties to check the model's integrity*
  -> *(p) progress properties - "something good will happen finally"*
  -> *(s) safety properties - "something bad never happens"*
  . . .

functional requirements

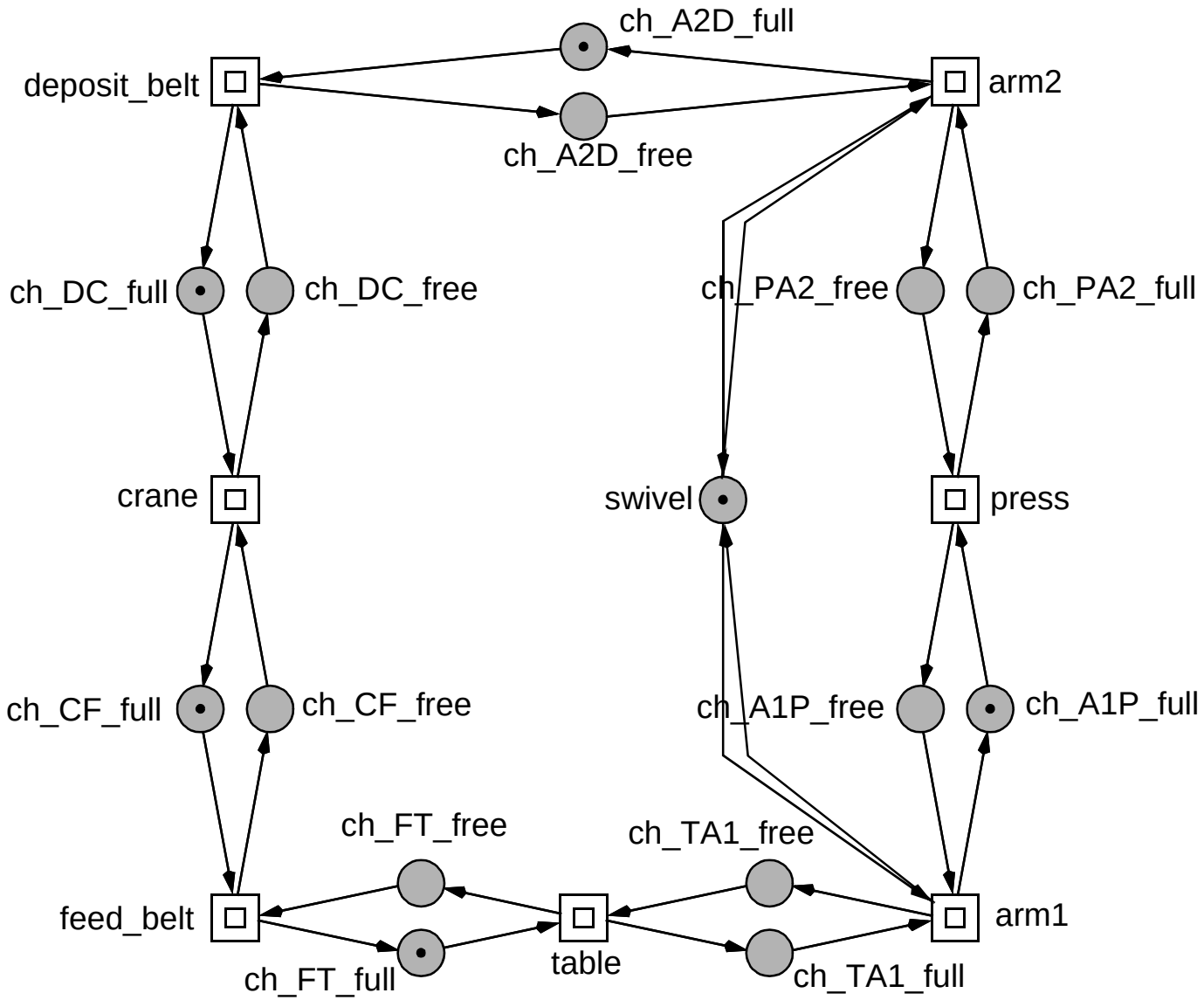
SAFETY VERSUS FUNCTIONAL REQUIREMENTS



EXAMPLE - PRODUCTION CELL (PC)



EXAMPLE PC - CLOSED SYSTEM, COARSE STRUCTURE



231 P,
202 T,
65 PAGES

- **insights (i)**
  - -> *Is it possible that both robot arms hold a plate simultaneously ?*
  - -> *How many plates can be concurrently inside the system ?*

- **consistency (c)**
  - -> *The robot swivel is always positioned at exactly one angle.*
  - -> *At any time, a robot arm can be driven in one direction only.*

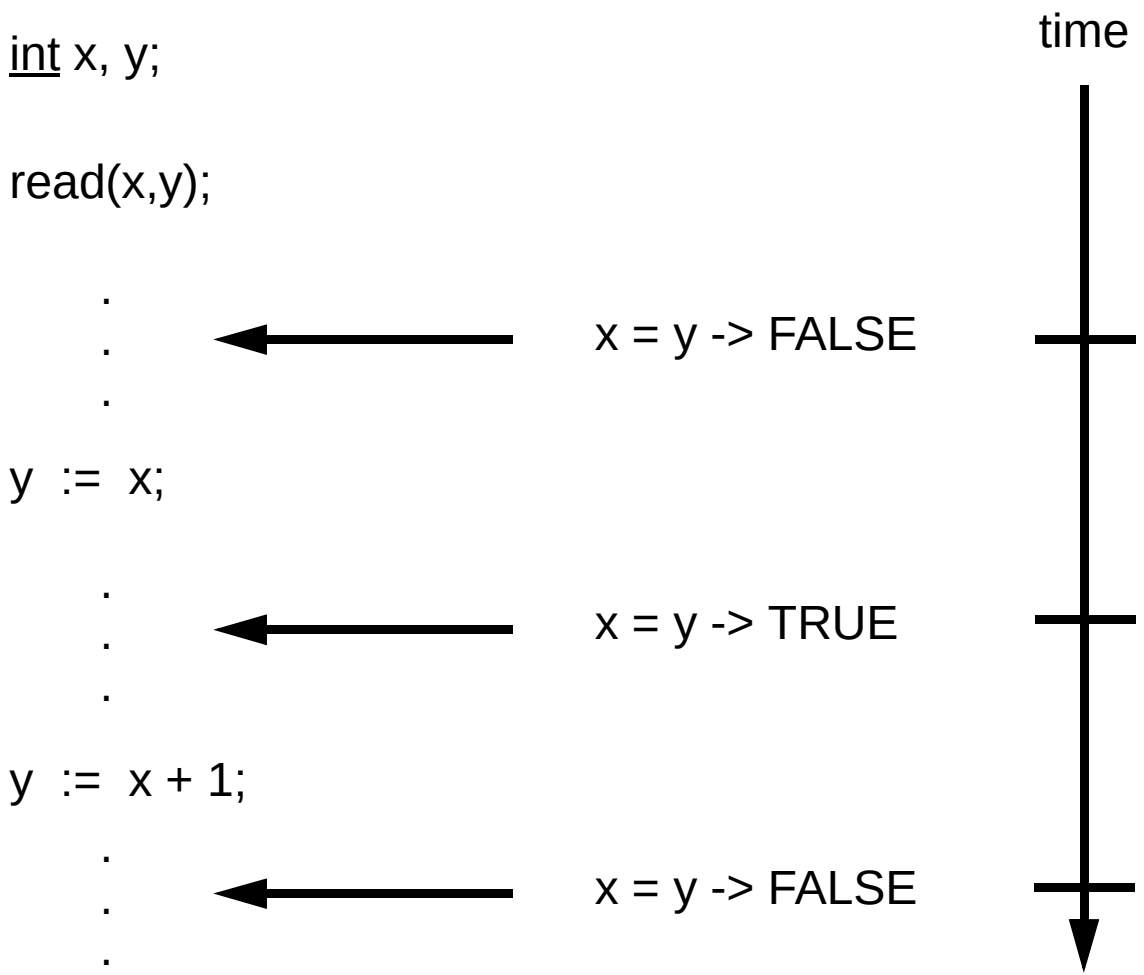
- **progress (p)**
  - -> *Any plate at the input position will finally reach the cell's output position.*

- **safety (s)**
  - -> *To avoid machine collisions,*
    the robot will only rotate with arms retracted.
  - -> *The press will only be closed, when no robot arm is positioned inside.*
  - -> *The feed belt may only convey a blank through its light barrier,*
    if the table is in its loading position.

MOTIVATION (2)

- **some properties can be expressed as un-/reachability of a given system state (marking)**
  - -> *safety property -> unreachability*
  - -> *(weak) progress property -> reachability*
- **BUT, system states (marking) tend to be lengthy**
  - -> *hard to read*
  - -> *error-prone specification*
- **most properties can not be expressed as un-/reachability of a given system state (marking)**
- **wanted: general query language to specify any special property**
  - -> *flexible*
  - -> *readable*

} ***temporal logics***



How to specify logical statements
with respect to the execution of a system ?

- **extension of classical (propositional) logics by temporal operators**

- **atomic propositions**
  - -> *elementary statements, having - in a given state - a well-defined truth value*
  - -> *e. g. fork1,* *for 1-bounded Petri net* *(Boolean)*
  - -> *e. g. buffer = 2, buffer > 2,* *else* *(Integer)*

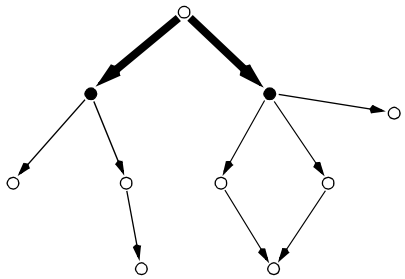
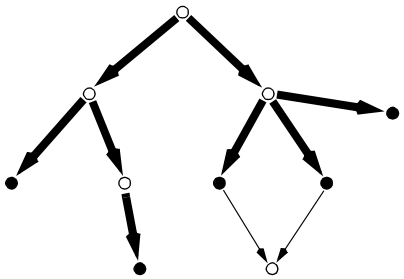
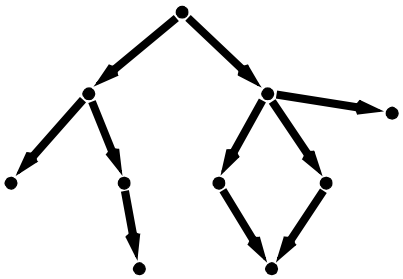
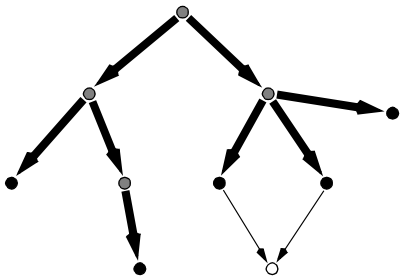
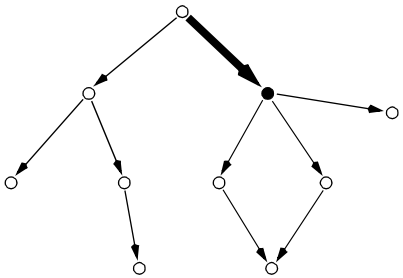
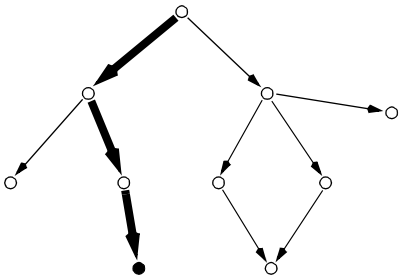
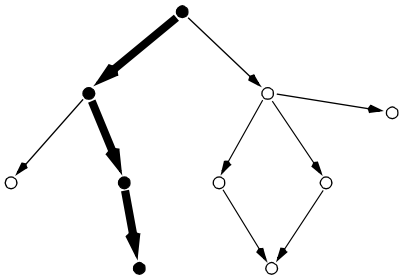
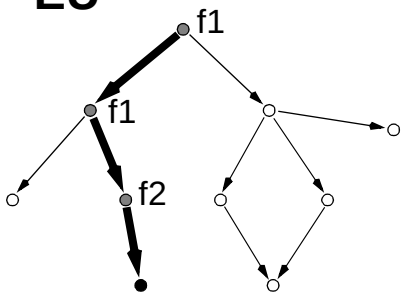
- **constants**
  - -> *TRUE, FALSE*

- **classical Boolean operators**

negation	*!*	*conjunction*	***
disjunction	*+*	*implication*	*->*

- **temporal operators**
  - -> *to refer to sequences of states*

CTL Operators, Interleaving Semantics

	next f	finally f	globally f	f1 until f2
on all paths	AX 	AF 	AG 	AU 
on some path	EX 	EF 	EG 	EU 

EXAMPLE TP - SOME SIMPLE PROPERTIES (1)

- **this is a possible combination of choices**

  EF *(hotel * car);* *-> TRUE*

- **this is the only possible combination of choices**

  AF *(hotel * car);* *-> FALSE*

- **this is an impossible combination of choices**

  ! ***EF*** *(train * car);* *-> TRUE*

- **any travel planning will be finished finally**

  AG *(next_vacation -> AF (ready));* *-> TRUE*

- **atomic use of the phone only,**
  the phone is never reserved over several steps

  AG *(phone);* *-> TRUE*

- **liveness of transition end_preparations**

  AG (EF *(accommodation * transport_means * luggage));* *-> TRUE*

EXAMPLE TP - SOME SIMPLE PROPERTIES (2)

- **livelock freedom/progress of transition end_preparations**

  AG *(****AF*** *(accommodation * transport_means * luggage));* *-> TRUE*

- **undone luggage will always be done in one step**

  AG *(luggage_open -> **AX** (luggage));* *-> FALSE*

- **it's possible that undone luggage will be done in one step**

  AG *(luggage_open -> **EX** (luggage));* *-> TRUE*

- **undone luggage will be done finally**

  AG *(luggage_open -> **AF** (luggage));* *-> TRUE*

- **luggage will remain undone until it is done**

  A *(luggage_open **U** luggage);* *-> FALSE*

- **if the luggage is undone, it remains undone until it is done**

  AG *(luggage_open -> **A** (luggage_open **U** luggage));* *-> TRUE*

- **reachability-related** **EF (φ)**
  -> *There exists at least one computational path to reach eventually a state, where φ will be true.*

- **safety-related** **AG (! φ)** **-> equivalent to ! EF (φ)**
  -> *For every computational path, φ will never be true.*

- **invariant-related** **AG (φ)** **-> equivalent to ! EF (! φ)**
  -> *For every computational path, φ will be true for ever.*

- **liveness-related** **AG (EF (φ))**
  -> *What ever happens, there exists the chance (at least one computational path) that φ will be true again.*

- **progress-related** **AG (AF (φ))**
  -> *For every computational path, φ will eventually be true.*

- **insights / reachability**

  -> *Is it possible, that both robot arms carry a plate at the same time?*

  EF *(arm1_mag_on * arm2_mag_on)*

- **consistency property**

  -> *The swivel is always either stopped or moves in exactly one direction.*

  G *(robot_stop xor robot_left xor robot_right)*

- **safety property**

  -> *If a robot arm is loaded, its magnet is not deactivated until the robot is in its unloading position.*

  AG *(φ -> **A** (!arm1_mag_off **U** ψ)), with*

  φ *= arm1_mag_on * arm1_pickup_angle * arm1_pickup_ext*

  ψ *= arm1_release_angle * arm1_release_ext*

  -> *The feed belt may only convey a blank through its light barrier, if the table is in its loading position.*

  *G (belt1_light_barrier_true -> (table_load_angle * table_bottom_pos))*

BOTTLENECK:
STATE EXPLOSION
(NO PRIMITIVE RECURSIVE FUNCTION ...)

DINING PHILOSOPHERS 1000, BDD-BASED

Number of places/marked places/transitions: 7,000/2,000/5,000 *[JSP 2001]*

Number of states:

113751760865620516280672035436276768405854187694780001109285823216991 8\\
159959588122031332641120690971790713407413960379370132051412946235771 0\\
244289522738424241885324723952294300718880861927052755597203329394869 1\\
334498271287409035878953318171137286359195790723689557093738307422542 1\\
493299735055934871120872608511650262781852464476299128123872281683542 6\\
439043702222222716712699874004961590120093014497021663026892511863169 6\\
792192797756430854076755677722422066045029462353435568315492194903488 7\\
413893510872611522753508464671945735340847108696533249480549775338294 2\\
171781101168772051021154169003921176627995642292903237688541475038527 5\\
512488192401053636525511904747774118 74

ca. 1.1 * 10^667

Number of places/marked places/transitions:	*7000/2000/5000*
Time to compute P-Invariants:	*45885.66 sec*
Number of P-Invariants:	*3000*
Time to compute compact coding:	*385.59 sec*
Number of Clusters:	*3000*
Number of Variables:	*4000*
Time:	*3285.73 sec, ca. 54.75 min*

POSSIBLE ANSWERS TO STATE EXPLOSION

- **compositional methods**
  -> *simple interfaces between modules*
- **abstraction by ignoring some state information**
  -> *conservative approximation*
- **different logics -> different algorithms, e.g. LTL**
- **integer programming**
- **compressed state space representations**
  -> *BDD, IDD, ...*
- **lazy state space construction**
  -> *partial order methods*
- **alternative state spaces**
  -> *partial order representations, e.g. prefix*

'BASE CASE' TECHNIQUES

'ALTERNATIVE' METHODS (PN)

SUMMARY MODEL CHECKING (1)

- **model checking can only be as good as the model specification**
  - -> *readable <-> unambiguous*
  - -> *complete <-> limited size*
- **correct model checking requires correct requirement specifications**
  - -> *take your time, think twice*
- **model checking proves consistency of**
  - -> *model & requirements*
- **if the answer is NO (-> FALSE)**
  - -> *the model can be wrong*
  - -> *the requirements can be wrong*
  - -> *or both*
- **if the answer is YES (-> TRUE)**
  - -> *model & requirements can still contain (same) logical faults* -> *unlikely !?*

SUMMARY MODEL CHECKING (2)

- **(up to now) restricted to bounded systems**
  - -> *numerous ongoing research*
  - -> *CTL - undecidable*
  - -> *LTL - decidable, but no tools (not yet ?)*
  - -> *unboundedness + inhibitor arcs = undecidability*
- **model checking may be extremely time and resource consuming**
  - -> *'external' quality pressure*
- **model checking is not manageable without theory supported by tools**
- **model checking needs knowledgeable professionals**
  - -> *study / job specialization*
  - -> *profession of "software validator", "software tester"*
- **There is no such thing as a fault-free model (system) !**
  - -> *sufficient dependability for a given user profile*

MODEL CHECKING
IS NO SUBSTITUTE FOR THINKING !

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