Core Course Preview

Introduction to Model Checking

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Model Checking

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- *to expose potential software design errors;*
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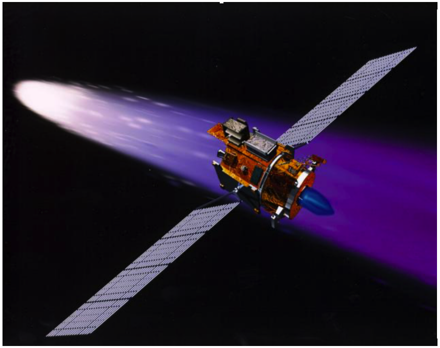
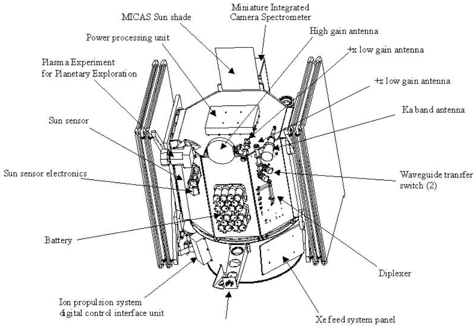
Course Goals are introduction to:

- Theory:
    - modeling systems by labeled transition systems,
    - expressing properties by temporal-logic formulas
    - model-checking algorithms
- Practice: use the Maude system for examples

Deep Space 1 (NASA)





- Flyby of asteroid 9969 Braille (1999)
- Entered the coma of Comet Borrelly (2001)
- Model checking discovered 5 concurrency errors

Example (program concurrency/non-determinism)

Programs Inc, Dec, and Reset cooperate, and use a shared variable x:

```
proc Inc
  while true
    do
      if x < 200
        then x := x + 1
      fi
    od
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proc Dec
  while true
    do
      if x > 0
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proc Reset
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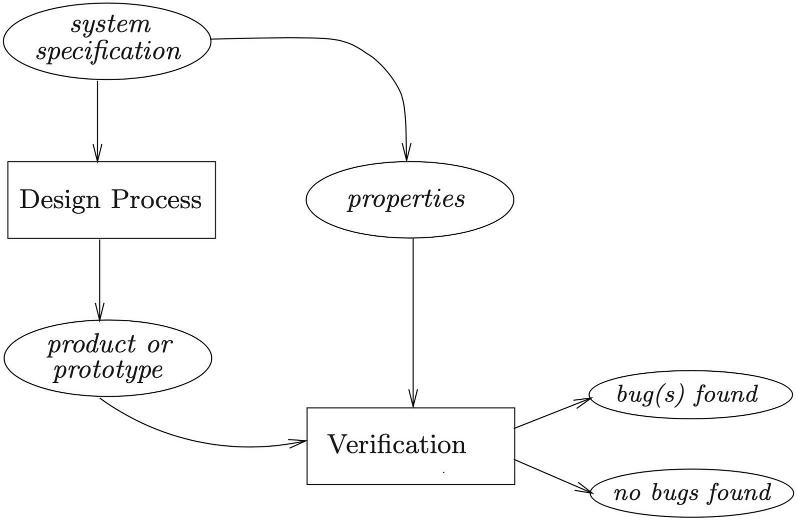
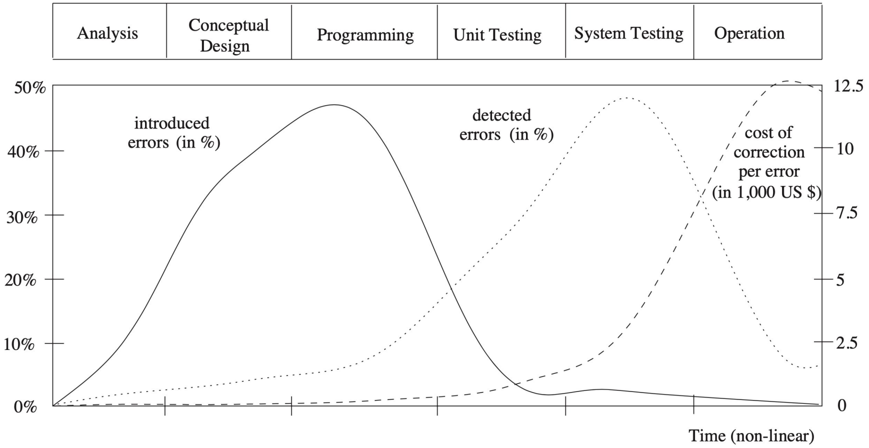
Question: Is $0 \leq x \leq 200$ always guaranteed?

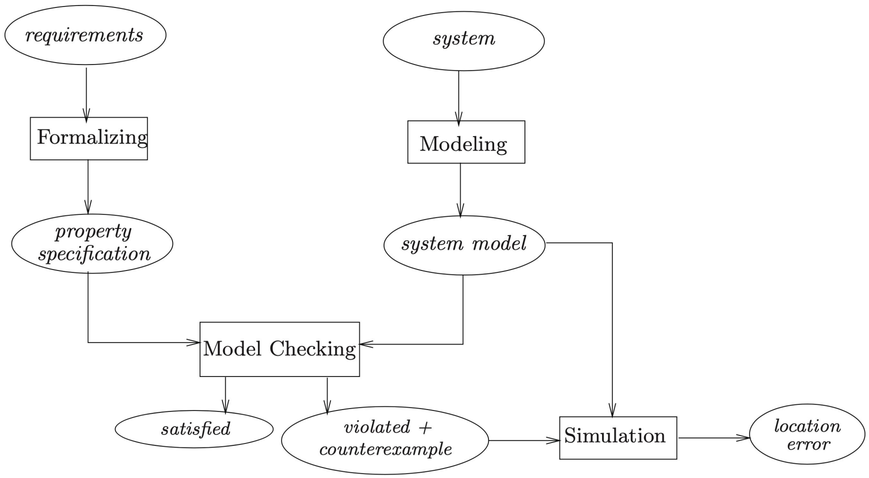
Hard-/Software Verification (traditionally)



Error introduction, detection, and repair costs



Model checking



Modeling (by program graphs)

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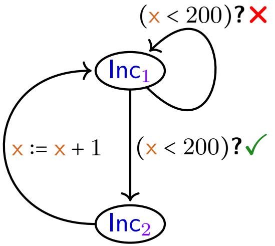
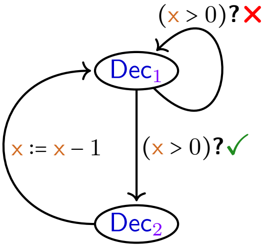


$$\begin{tikzcd} \mathrm{Inc}_1 \arrow[loop right, "(x<200)?\,✗"] \arrow[d, "(x<200)?\,✓"] \\ \mathrm{Inc}_2 \arrow[u, bend left=60, "x := x+1"] \end{tikzcd}$$



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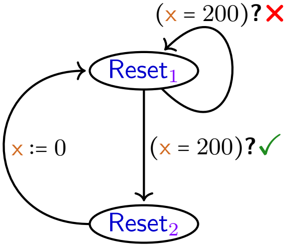

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Program graphs (PG)

Modeling (by labeled transition systems, with state space explosion)

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{l_2,\ x = -1} \arrow[d, "x := x + 1"] \\
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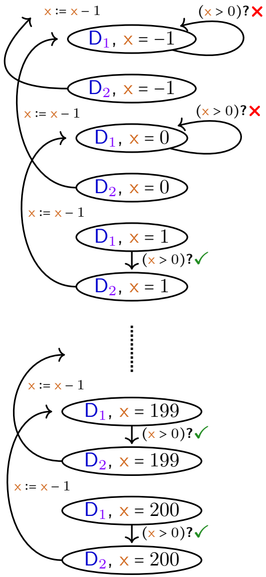

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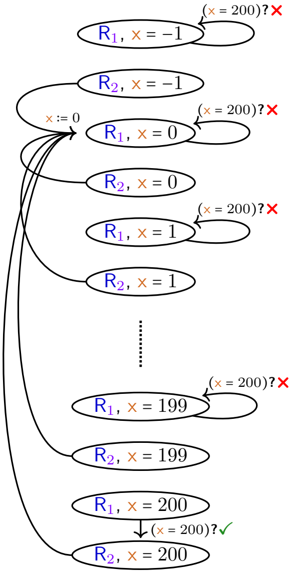

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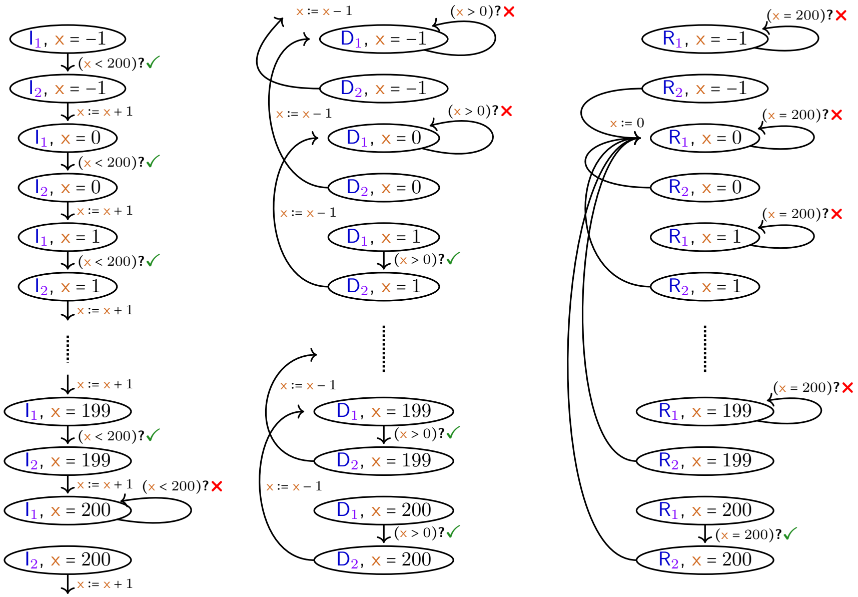
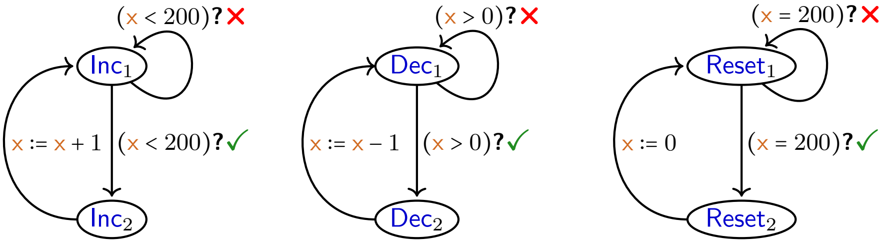


Formalizing properties (in temporal logic)



$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \overset{?}{\models} \Box(0 \leq x \wedge x \leq 200)$ (Linear-TL formula)

Counterexample (offending execution trace)

$$\boxed{\left\langle x = 199\,;\ \mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \right\rangle}$$

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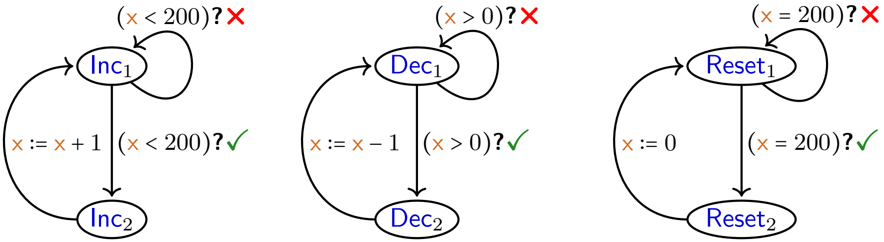
Formalizing properties (in temporal logic)



$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \not\models \Box(0 \le x \wedge x \le 200)$ (Linear-TL formula)

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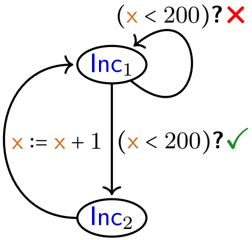
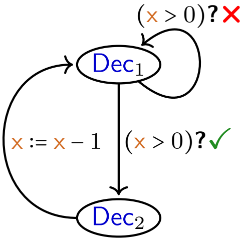
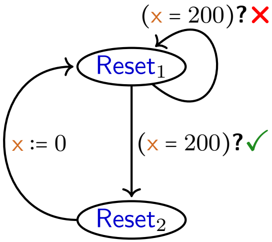
$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \not\models \Box(0 \leq x \wedge x \leq 200)$ (Linear-TL formula)

$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \models \Diamond(x < 0)$ (LTL formula)

Formalizing properties (in temporal logic)







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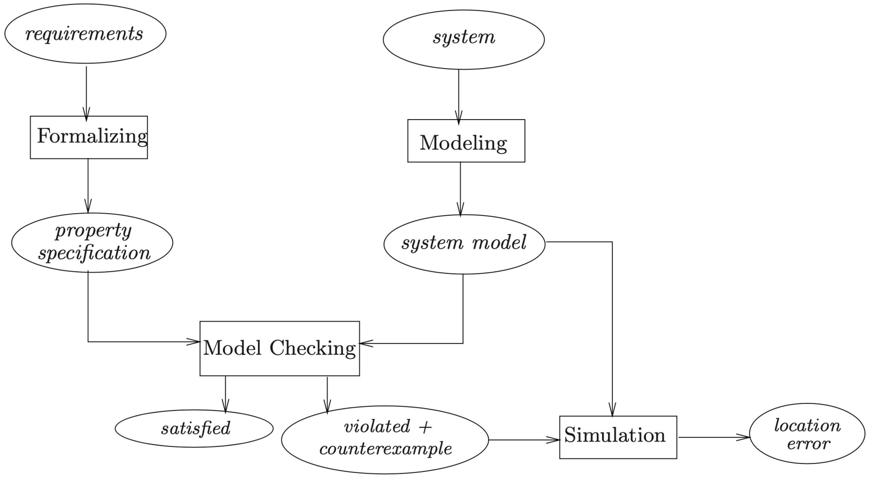
$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1$	$\models$	$\Diamond(x < 0)$	(LTL formula)
$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1$	$\not\models$	$\forall\Box(0 \leq x \,\wedge\, x \leq 200)$	(Computation-Tree-L formula)
$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1$	$\models$	$\exists\Box(0 \leq x \,\wedge\, x \leq 200)$	(CTL formula)
$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1$	$\models$	$\forall\Box\exists\Diamond(x < 0)$	(CTL formula)

Model checking



Any [such] verification is only as good as the model of the system.

Possible Maude code (idea)

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crl [Inc1a]   :  Inc1 x => Inc2 x  if x < 200
rl  [Inc2]    :  Inc2 x => Inc1 x + 1
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crl [Reset1a] :  Reset1 x => Reset2 x  if x = 200
rl  [Reset2]  :  Reset2 x => Reset1 0
crl [Reset1b] :  Reset1 x => Reset1 x  if not(x = 200)
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crl [Reset1a] :  Reset1 x => Reset2 x  if x = 200
rl  [Reset2]  :  Reset2 x => Reset1 0
crl [Reset1b] :  Reset1 x => Reset1 x  if not(x = 200)


eq initial = { Dec1 Inc1 Reset1 199 }
```

Possible Maude code (idea)

```
crl [Inc1a]   :  Inc1 x => Inc2 x  if x < 200
rl  [Inc2]    :  Inc2 x => Inc1 x + 1
crl [Inc1b]   :  Inc1 x => Inc1 x  if not(x < 200)

crl [Dec1a]   :  Dec1 x => Dec2 x  if x =/= 0
rl  [Dec2]    :  Dec2 x => Dec1 x - 1
crl [Dec1b]   :  Dec1 x => Dec1 x  if x = 0

crl [Reset1a] :  Reset1 x => Reset2 x  if x = 200
rl  [Reset2]  :  Reset2 x => Reset1 0
crl [Reset1b] :  Reset1 x => Reset1 x  if not(x = 200)

eq initial = { Dec1 Inc1 Reset1 199 }

ceq (S1 S2 S3 x |= counterge0) = true  if (0 < x \/ x = 0)
ceq (S1 S2 S3 x |= counterlt0) = true  if (x < 0)
ceq (S1 S2 S3 x |= counterle200) = true  if (x < 200 \/ x = 200)
```

Maude output

```
Maude> red modelCheck(initial, <> counterlt0)
reduce in COUNTERS-CHECK : modelCheck(initial, <> counterlt0)
result ModelCheckResult:
result Bool :  true
```

Maude output

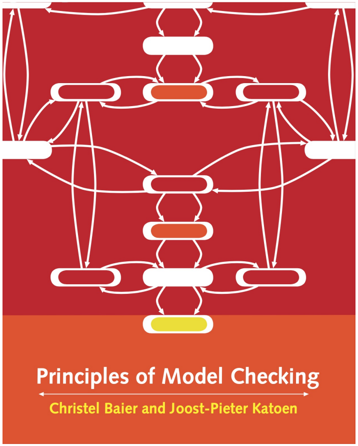
```
Maude> red modelCheck(initial, <> counterlt0)
reduce in COUNTERS-CHECK : modelCheck(initial, <> counterlt0)
result ModelCheckResult:
result Bool :  true


Maude> red modelCheck(initial, [](counterge0 /\counterle200)
reduce in COUNTERS-CHECK :
                modelCheck(initial, [](counterge0 /\counterle200)
result ModelCheckResult:
counterexample({Inc1 Dec1 Reset1 199}
                {Inc2 Dec1 Reset1 199}
                {Inc1 Dec1 Reset1 200}
                {Inc1 Dec2 Reset1 200}
                {Inc1 Dec2 Reset2 200}
                {Inc1 Dec2 Reset1 0}
                {Inc1 Dec1 Reset1 -1})
```

Topics of the course

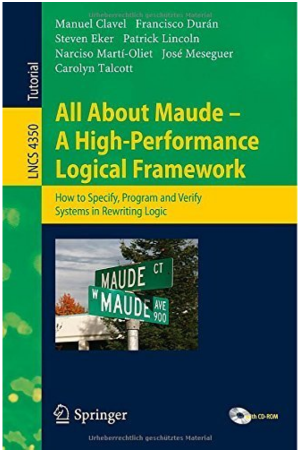
- modeling systems by labeled transition systems (LTSs)
- safety, liveness, and fairness properties
- Linear Temporal Logic (LTL)
  - model checking formulas
    - express properties by Büchi automata
    - model check LTSs and properties via product automata
- Computation Tree Logic (CTL)
- partial model checking
  - partially known systems (state properties/states/transitions)
- learning Maude and its model-checker

Book


Principles of Model Checking
Christel Baier and Joost-Pieter Katoen

- pdf available:
  https://is.ifmo.ru/books/_principles_of_model_checking.pdf

Book Maude


Manuel Clavel Francisco Durán
Steven Eker Patrick Lincoln
Narciso Martí-Oliet José Meseguer
Carolyn Talcott
Tutorial
LNCS 4350
All About Maude – A High-Performance Logical Framework
How to Specify, Program and Verify Systems in Rewriting Logic
MAUDE CT
W MAUDE AVE 900
Springer
with CD-ROM

- pdf available:
  https://maude.cs.illinois.edu/w/images/0/0d/Maude-book.pdf

Organization

Lectures (Emilio 3 / Clemens 4)

- January 19 – January 28 (7 meetings)
- blackboard presentations
- notes after the lecture (last year's notes available)
- Maude examples at the end of each lecture

Webpage

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- options:
  - verification project (of an algorithm, etc.) in Maude
  - presentation about a paper
  - written exam

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Thank you – we are looking forward to the course!