Model Checking with SPIN

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⇒ inspired by slides on SPIN by Theo Ruys, Gerard Holzmann, and Diego Latella
Outline

• model checking

• SPIN in brief

• Promela models

• LTL formulae

• some theory

• Xspin in brief

• a case study
Model Checking

an automatic technique to verify if a concurrent system design satisfies its specifications

very hard in standard ways (like, e.g., testing) due to non-determinism & interleaving

+ exhaustive verification, i.e. takes into account all possible input combinations & states

– risk of running out of memory due to a state-space explosion

⇒ a simplified model is used, still capturing the core of the system design while abstracting from unnecessary details

SPIN among the most powerful model checkers
Model Checking Approach

Model $M$

```java
byte n;
proctype Inc()
{
    do
        :: n++
    od
}
```

Property $\phi$

$[\neg (n < 3)]$

Model Checker $M \models \phi$

YES

(property satisfied)

NO

(counter-example)
SPIN – Simple Promela INterpreter

a state-of-the-art & on-the-fly model checker developed at Bell Labs by Gerard Holzmann:

Design and Validation of Computer Protocols


The Spin Model Checker—Primer and Reference Manual


⇒ winner ACM System Software Award ’01
**SPIN in brief**

formal verification of concurrent systems (esp. communication protocols) specified in Promela

verifies deadlocks / assertions / unreachable code / LTL formulae / liveness / etc.

provides counterexample if property is violated

based on over two decades of research on CAV

very well documented: [http://spinroot.com](http://spinroot.com) and scientific literature

very nice user-friendly graphical interface: Xspin
Model Checking with SPIN

1. write abstract Promela model of a system

2. formalise correctness properties (e.g. LTL)

3. run the model checking algorithm of SPIN

4. interpret one of the three possible results:
   - the model satisfies the property \( \sqrt{ } \)
   - the model can violate the property \( \Rightarrow \) study the given counterexample
   - insufficient resources to solve problem \( \Rightarrow \) construct a more abstract model

5. revise 1 or 2 & repeat 3–5 until satisfied
Promela – PROcess MEta LAnguage

non-deterministic C-like specification language

allows dynamic creation of concurrent processes

(very large) finite-state systems communicating through channels: synchronous (rendez-vous) or asynchronous (buffered)

borrows notation for I/O operations from CSP

loosely based on Dijkstra’s guarded commands

interleaving semantics: processes interleaved, statements atomic (except for the rendez-vous communication)
Promela Model

macros

#define numUsers 3

type declarations

mtype = {get, got, ...};

channel declarations

chan userToCC = [0] of {mtype, byte};
chan ccToUser[numUsers] = [1] of {mtype};

variable declarations

bool waitingForCheckedOut;

process declarations

proctype User(byte id) {...}

initialisation process

init {...}
Defining a Process

A process type (proctype) consists of name; list of parameters; local variable declarations; body

```proctype User(byte id) {
  byte edit[numFiles], registered[numFiles];
  bool waitingForCheckedOut = false;
  do
    :: (!waitingForCheckedOut) ->
      userToCC!get,id;
    doneGet: skip;
    ccToUser[id]?got;
    registered[0] = true
    :: ... 
    :: (!edit[0] && !waitingForCheckedOut) ->
      waitingForCheckedOut = true;
    userToCC!checkOut,id
  od
}
```
Functioning of a Process

A process is created using the `run` statement (which returns the process id) \( \text{run User(1);} \)

A process may be created at any point of the execution (within any process)

A process starts executing the moment it is run

There may be several processes of the same type, but each process has its own local state (proctype location + contents local variables)

A process communicates with other processes by using channels or global—shared—variables
Types and Variables

type conflicts are detected at runtime

basic types       bit, bool, byte, short, int

arrays           byte edit[numFiles];
(indicating starts at 0) bit flags[4];

records          typedef Record { bit r1; byte r2 };  

variables must be declared Record rec;

variables are initialised by argument/message passing or by assignment rec.r1 = 2

default initial value of basic variables is 0

variables can be used in expressions
**Statements**

a process body consists of a list of statements

a statement is either executable or blocked; an assignment is always executable

an expression is a statement; executable if it evaluates to non-zero \( 2 < 3; \ x < 3; \ 3 + x \)

the `skip` statement is always executable; often used to label point in code \( \text{doneGet:skip;} \)

the `assert(exp)` statement is always executable; if `exp` evaluates to 0, SPIN exits with an error; often used to check whether a property is valid in a state \( \text{assert(writeLock == false);} \)
if- and do-statements

if/do
  :: ...
  :: guard₁ -> stat₁₁; stat₁₂; ...
  :: ...
fi/od;

the statement is executable if at least one guard is executable; otherwise it is blocked

by non-deterministically choosing to execute one of the executable guards, the statement is executed (for the do-statement the choice is repeated)

the else guard in an if-statement becomes executable if no other guard is executable

the break statement in a do-statement is always executable and exits a do-loop
Communication via Channels

```plaintext
chan userToCC = [0] of {mtype, byte};

name dimension = 0 type of elements
(rendez-vous) transmitted

chan ccToUser[numUsers] = [1] of {mtype};

array of channels FIFO buffer of
dimension = 1
```
Asynchronous Communication

! send: put a message into a channel

ccToUser[id]!got;

got should be of the declared type;
executable if the channel is not full

? receive: get a message out of a channel

ccToUser[id]?got;

executable if the channel is not empty;
the first message is removed from the channel and stored in / if equal to got

(message passing / message testing)
Synchronous Communication

a.k.a. rendez-vous or handshake communication

the number of elements in the channel is zero

proctype User(byte id)
{
    ...
    userToCC!get,id;
    ...
}

proctype CC()
{
    byte id; ...
    userToCC?get,id
    ...
}

if both statements are executable and both get and id match, then the statements can be executed simultaneously and CC’s id := User’s id
State Vector

the info to uniquely identify a system state:

• global variables
• channel contents
• for each process:
  – local variables
  – process counter

it is important to **minimise** the state vector:

\[
\text{state vector: } m \text{ bytes} \quad \Rightarrow \quad \text{storing the state space may require } n \times m \text{ bytes}
\]

$\Rightarrow$ SPIN provides a number of algorithms to reduce the size of the state vector
Reducing the Size of the State Vector

partial order reduction (enabled by default)
  if in global state a process can execute only local statements, let other processes wait

bitstate hashing
  do not store state explicitly, use only 1 bit

hash compaction; state vector compression; slicing; minimised automaton (effective but slow)

limit the number of processes: combine some

since all data ends up in the state vector:
  • limit the values a variable can be assigned
  • limit the dimension of (buffered) channels
  • prefer local variables over global variables
Reducing the Number of States

atomic{run Vault(); run CC(); run User(1); ...}

all statements are executed in a single step; no interleaving with statements of other processes is executable if the first statement is executable

no pure atomicity: blocks if a statement blocks

d_step{edit[0] = true;
    waitingForCheckedOut = false}

is a more efficient version of atomic: no intermediate states are generated and stored

may only contain deterministic steps; causes a runtime error if a statement blocks
Properties

recall model checking tools automatically verify

finite-state model of some system \( M \models \phi \) property in some formal notation

\textbf{safety}: “nothing bad ever happens”

SPIN: find a computation leading to the ‘bad’ thing; if there is no such computation, the property is satisfied

\textbf{liveness}: “something good eventually happens”

SPIN: find a loop in which the ‘good’ thing does not happen; if there is no such loop, the property is satisfied

\( \Rightarrow \) we need a precise way to express properties
LTL – Linear Temporal Logic

introduced by Amir Pnueli in the late 1970’s

a propositional logic with temporal operators

always / eventually / until / etc.

direct link with the theory of Büchi automata

⇒ ideal to specify liveness properties in SPIN
Syntax of LTL in SPIN

LTL formula ::= 
    true, false 
    propositional symbols p, q, . . . 
    (f), unary f, f binary f

unary ::= 
    [] \hspace{1cm} \text{(always, henceforth)}
    <> \hspace{1cm} \text{(eventually)}
    ! \hspace{1cm} \text{(logical negation)}

binary ::= 
    U \hspace{1cm} \text{(strong until)}
    && \hspace{1cm} \text{(logical and)}
    || \hspace{1cm} \text{(logical or)}
    -> \hspace{1cm} \text{(logical implication)}
    <-> \hspace{1cm} \text{(logical equivalence)}
Temporal Semantics of LTL

if \( \alpha = q_0a_1q_1 \cdots a_iq_i \cdots \) is a computation, then:

\[ \alpha \models f \iff q_0 \models f \]

with

\( q_i \models [] f \iff \forall k \geq i : q_k \models f \)

\( q_i \models <> f \iff \exists k \geq i : q_k \models f \)

\( q_i \models e \cup f \iff (\exists k \geq i : q_k \models f \quad \text{and} \quad \forall i \leq j < k : q_j \models e) \)
Typical LTL formulae

\[ \text{always } p \quad \text{invariance} \]
\[ \text{eventually } p \quad \text{guarantee} \]
\[ p \rightarrow (<> q) \quad p \text{ implies eventually } q \quad \text{response} \]
\[ p \rightarrow (q \mathcal{U} r) \quad p \text{ implies } q \text{ until } r \quad \text{precedence} \]
\[ \text{always eventually } p \quad \text{recurrence} \]
\[ \text{(progress)} \]
\[ <> [] p \quad \text{eventually always } p \quad \text{stability} \]
\[ \text{(no progress)} \]
\[ <> p \rightarrow <> q \quad \text{eventually } p \text{ implies eventually } q \quad \text{correlation} \]

user can always eventually get a document

\[ [] <> \text{User[pid]@doneGet} \]
\[ \text{id User process label} \]
SPIN’s Model Checking Algorithm

SPIN uses a depth first search algorithm to generate and explore the complete state space simultaneously construction and error checking: SPIN is an on-the-fly model checker.

Promela processes $P_1, P_2, \ldots, P_n$ property $\phi$

$\downarrow$ interleaving $\downarrow$

Büchi automaton $\neg \phi$

$\downarrow$ translation $\downarrow$

language intersection $\iff$ Büchi automaton

(should be empty) (never claim)
Underlying Theory

\[ \mathcal{L}(\text{model}) = \bigcup \mathcal{L}(\text{processes}) \]

\[ \mathcal{L}(\text{model}) \subseteq \mathcal{L}(\text{property}) \]

\[ \mathcal{L}(\text{model}) \cap (\Sigma^\omega \setminus \mathcal{L}(\text{property})) = \emptyset \]

i.e.

\[ \mathcal{L}(\text{model}) \cap \mathcal{L}(\neg \text{property}) = \emptyset \]

logical negation of the property

\[ I = \emptyset: \text{ the model satisfies the property} \]

\[ I \neq \emptyset: \text{ the model can violate the property and } I \text{ contains at least one counterexample} \]
Finite Automaton

\[ \mathcal{A} = (Q, \Sigma, \delta, I, F) \]

- **Q** finite set of states
- **\Sigma** finite set of letters/symbols: alphabet
- \( \delta \subseteq Q \times \Sigma \times Q \) transition relation
  \( q \xrightarrow{a} q' \)
- **I \subseteq Q** set of initial states
- **F \subseteq Q** set of final states

\[ \alpha = q_0 a_1 q_1 \cdots a_n q_n \] with \( q_0 \in I \) and \( (q_{i-1}, a_i, q_i) \in \delta \)
for all \( 1 \leq i \leq n \) is a (finite) computation of \( \mathcal{A} \)

\( \alpha \) is accepting if \( q_n \in F \), in which case the (finite) word \( a_1 a_2 \cdots a_n \) is accepted by \( \mathcal{A} \)

\[ \mathcal{L}(\mathcal{A}) = \{ w \in \Sigma^* \mid w \text{ is a word accepted by } \mathcal{A} \} \]

is the (finitary) language of \( \mathcal{A} \)
Finite Automata $A$, $A_1$, and $A_2$

$L(A_1 \cup A_2) = L(A_1) \cup L(A_2)$ polynomial

$L(A_1 \cap A_2) = L(A_1) \cap L(A_2)$ polynomial

deterministic and non-deterministic FA equally expressive, but determinisation is exponential

$\overline{A}$ complement of $A$
$\Sigma$ alphabet of $A$

$L(\overline{A}) = \Sigma^* \setminus L(A)$ exponential if $A$ non-deterministic

$L(A) = \emptyset?$ linear
Büchi Automaton

a FA \( A = (Q, \Sigma, \delta, I, F) \) with Büchi acceptance:

\[ \alpha = q_0 a_1 q_1 \cdots \] with \( q_0 \in I \) and \((q_{i-1}, a_i, q_i) \in \delta\) for all \( i \geq 0 \) is an infinite computation of \( A \)

\( \alpha \) is accepting if there exists a \( q_j \in F \) that appears infinitely often in \( \alpha \), in which case the infinite (or \( \omega \)-) word \( a_1 a_2 \cdots \) is accepted by \( A \)

the stutter extension rule is used to extend a finite computation \( q_0 a_1 q_1 \cdots a_n q_n \) to the infinite computation \( q_0 a_1 q_1 \cdots a_n q_n (\lambda q_n)^\omega \)

\[ \mathcal{L}_\omega(A) = \{ w \in \Sigma^\omega \mid w \text{ is a word accepted by } A \} \] is the infinitary or \( \omega \)-language of \( A \)
Büchi Automata $\mathcal{A}$, $\mathcal{A}_1$, and $\mathcal{A}_2$

$L_\omega(\mathcal{A}_1 \cup \mathcal{A}_2) = L_\omega(\mathcal{A}_1) \cup L_\omega(\mathcal{A}_2)$  polynomial

$L_\omega(\mathcal{A}_1 \cap \mathcal{A}_2) = L_\omega(\mathcal{A}_1) \cap L_\omega(\mathcal{A}_2)$  polynomial

non-deterministic Büchi automata strictly more expressive than deterministic Büchi automata!

$\bar{\mathcal{A}}$ complement of $\mathcal{A}$

$\Sigma$ alphabet of $\mathcal{A}$

$L_\omega(\bar{\mathcal{A}}) = \Sigma^\omega \setminus L_\omega(\mathcal{A})$  exponential, $\bar{\mathcal{A}}$ may be non-deterministic

$L_\omega(\mathcal{A}) = \emptyset$?  linear
From LTL to Büchi Automata

**Theorem**: for any LTL formula $f$ there exists a Büchi automaton that accepts precisely those infinite computations for which $f$ is satisfied

Pierre Wolper, Moshe Vardi, Aravinda Sistla’83

$<> [\square] p$ corresponds to the Büchi automaton:

![Büchi automaton diagram](image)

To turn a property into a never claim it suffices to negate it: $! <> [\square] p \equiv [\square] ! [\square] p \equiv [\square] <> ! p$

![Negated Büchi automaton diagram](image)
Xspin in brief

a nice graphical interface to help the user to:

- edit and syntax check Promela models
- simulate Promela models
  - random
  - interactive
  - guided
- verify Promela models
  - exhaustive
  - bitstate hashing
  - many options and directives to fine tune
- use additional features
  - draw automata for each process
  - easy-to-use LTL property manager
  - help (simulation & verification guidelines)
Case Study: thinkteam (TT)

think3’s Product Data Management application is a dispersed & asynchronous groupware system that provides PDM needs of design processes in the manufacturing industry.

Strengths: rapid deployment & startup cycle, flexible, smooth integration with thinkdesign (think3’s CAD solution) & 3rd party products, helps to capture, organise, automate & share engineering product information efficiently.

⇒ joint work with Mieke Massink, Diego Latella & Stefania Gnesi from FM&&T; Alessandro Forghieri & Maurizio Sebastianis from think3
Vaulting

(controlled storage and retrieval of documents)

TT’s vaulting subsystem:

(1) provides a single, secure & controlled storage environment, where the documents controlled by the PDM application are managed

(2) prevents inconsistent updates or changes to documents, while still allowing the maximal access compatible with the business rules whose implementation is:

(1) subject of vaulting subsystem’s lower layers

(2) in TT’s underlying groupware protocol by a standard set of operations on TT’s vault, a file-system-like repository
Operations on TT’s Vault

*get*: extract a read-only copy of a document

*import*: insert an external document

*checkOut*: extract an exclusive copy of a document (with the intent to modify it)

*checkIn*: replace an edited (& hence previously checked out) document

*checkInOut*: replace an edited document (while retaining it as checked out)

*unCheckOut*: cancel the effects of a *checkOut*
Adding Publish/Subscribe Notification

raise user awareness by intelligent data sharing:

“whenever a user publishes a document by sending it to the vault, automatically all users that are subscribed to that document are notified via an asynchronous multicast communication”

notion recently much studied in the literature:

+ “full decoupling of the communicating participants in time, space & flow” [EFGK03]

− generally difficult to verify [GKK03,ZGB03]

Aim: formally model & verify the addition of a publish/subscribe notification service to TT
every user can (un)subscribe to a document by an explicit (un)Register or by an implicit get

every user subscribed to a document receives:

- a notify the moment in which that document is checked out by another user

- an update the moment in which another user has returned that document to the vault via an unCheckOut, a checkIn, or a checkInOut
Most Important Assumptions

very low probability of competing user requests

⇒ most communication by handshake channels

there is only one document (file 0) in the vault

⇒ users currently cannot import any document

the notify & update action are always enabled

⇒ a UserAdmin process deals only with those

no message is ever lost
Simulation with SPIN for 3 users (1)

MESSAGE SEQUENCE CHART OF A RANDOM SIMULATION OF THE THINKTEAM PROTOCOL FOR 3 USERS
Simulation with SPIN for 3 users (2)

MESSAGE SEQUENCE CHART OF A RANDOM SIMULATION OF THE THINKTEAM PROTOCOL FOR 3 USERS
Simulation with SPIN for 3 users (3)

MESSAGE SEQUENCE CHART OF A RANDOM SIMULATION OF THE THINKTEAM PROTOCOL FOR 3 USERS
Validation with SPIN for 3 users

invalid endstate: SPIN’s formalisation of deadlock state

(Spin Version 4.1.3 -- 24 April 2004)
  + Partial Order Reduction
  + Compression

Full statespace search for:
  never claim - (none specified)
  assertion violations - (disabled by -A flag)
  cycle checks - (disabled by -DSAFETY)
  invalid end states +

State-vector 108 byte, depth reached 434033, errors: 0
1.86628e+06 states, stored
2.51414e+06 states, matched
4.38041e+06 transitions (= stored+matched)
  12 atomic steps
hash conflicts: 175055 (resolved)
(max size 2^23 states)

Stats on memory usage (in Megabytes):
223.953 equivalent memory usage for states (stored*(State-vector+overhead))
65.055 actual memory usage for states (compression: 29.05%)
  State-vector as stored = 23 byte + 12 byte overhead
33.554 memory used for hash table (-w23)
16.000 memory used for DFS stack (-m500000)
114.783 total actual memory usage

[...]

real 3:12.6
user 3:06.5
sys 1.3
all verifications were performed by running SPIN Version 4.1.3 on a SUN Netra X1 workstation with 1000 Mbytes of available physical memory

full state-space searches for deadlock states:

<table>
<thead>
<tr>
<th>users</th>
<th>state vector</th>
<th>depth reached</th>
<th>errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>84 byte</td>
<td>4423</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>108 byte</td>
<td>434033</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>132 byte</td>
<td>10484899</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>users</th>
<th>memory used</th>
<th>runtime</th>
<th>flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>37.574 Mbytes</td>
<td>0:0:01.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>114.783 Mbytes</td>
<td>0:03:06.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>916.095 Mbytes</td>
<td>8:18:36.5</td>
<td>-DMA = 28</td>
</tr>
</tbody>
</table>

(the runtime is given as hours:minutes:seconds)
Correctness Criteria of TT Protocol

Concurrency Control

1) every lock request is eventually answered
2) only one user at a time may possess a lock on a file
3) every file lock is eventually released
4) a file lock is not released after a checkInOut

Awareness

1) no user receives (a) a notify or (b) an update if not registered
2) every checkOut or checkInOut eventually leads to a notify to all (and only those) registered users
3) every unCheckOut, checkIn, or checkInOut eventually leads to an update to all (and only those) registered users

Denial of Service

1) no user is forever denied a service

⇒ formalise in LTL & verify with SPIN! (3 users)
CC-1: Respond to Lock

“every lock request is eventually answered”

[] (CC[2]@doneCheckOut ->

<> (CC[2]@doneCheckedOut ||

CC[2]@doneNotAvailable))

∀comp. ∀state: X_________X______

SPIN: valid ! (± 15 min.)

!(<> CC[2]@doneCheckOut)

SPIN: not valid, i.e. counterexample ! (<1 sec.)
CC-3: Release File+Lock

“every file lock is eventually released”

\[
[] (\text{CC}[2] @ \text{doneCheckedOut} \rightarrow
\]

\[
<> (\text{CC}[2] @ \text{doneCheckIn} ||
\]

\[
\text{CC}[2] @ \text{doneUnCheckOut})
\]

∀comp. ∀state: ______X__________________X______ - -

SPIN: not valid, i.e. counterexample! (<1 sec.)

“a user can endlessly perform checkInOut”

⇒ unavoidable property of TT protocol, which in TT practice is resolved by a ‘superuser’!
AW-1a: No Illegal Notify

“no user receives a notify w.r.t. a file
if not registered for it”


\(! (\neg (User[3]@doneGet \lor
\neg User[3]@doneRegister) \cup\neg UserAdmin[4]@doneNotify)
\]

\(\land \land [] (User[3]@doneUnRegister \rightarrow \varphi)\)

\[\neg get \land \neg register\]

\[\forall state : \underline{\land unRegister} \underline{\landnotify} \underline{\land not register} \]

SPIN: valid ! (± 20 min.)

(User[3] & UserAdmin[4] refer to user 0, but analogous formulae hold for users 1 & 2)
**AW-2: Notify if Registered**

“every checkOut eventually leads to a notify to all (and only those) users registered for checked out file”

\[
[] \text{!}((\text{CC}[2]@\text{doneGet}0 | | \text{CC}[2]@\text{doneRegister}0) \\
\& \& (< > \varphi) \& \& (! \text{CC}[2]@\text{doneUnRegister}0 \uplus \\
(\varphi \& \& []) ! \text{CC}[2]@\text{doneNotify}0)))
\]

where

\[\varphi = \text{CC}[2]@\text{doneCheckedOut}1 | |
\text{CC}[2]@\text{doneCheckedOut}2\]

\[\uprod\text{comp.} \uprod\text{state} : \begin{array}{c}
\begin{array}{c}
0: \text{get} \lor \text{register} \\
\hline
\hline
\end{array}
\end{array}
\begin{array}{c}
\begin{array}{c}
1 \lor 2: \text{checkedOut} \\
\hline
\hline
\end{array}
\end{array}\]

SPIN: valid! (± 40 min.)

(analogous formulae — in which users 0, 1 & 2 change roles — also hold)
DoS: Denial of Service

“no user is forever denied a service”

\[ [ ] <> \text{User}[\text{pid}] \oplus \text{doneGet} \]

where pid is 3 (user 0), 5 (user 1), or 7 (user 2)

\[ \forall \text{comp.} \forall \text{state: } \text{x} \]

SPIN: not valid, i.e. counterexamples! (<1 sec.)

“one user can endlessly keep the CC busy”

⇒ unavoidable property of TT protocol, due to document access based on retrial principle—i.e. no queue or file reservation system in TT

⇒ think3 interested in this for a future release!
**Results of Validation with SPIN**

<table>
<thead>
<tr>
<th>property</th>
<th>depth</th>
<th>errors</th>
<th>memory used</th>
<th>runtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC-1</td>
<td>2703909</td>
<td>0</td>
<td>597.471 Mb</td>
<td>14:57.0</td>
</tr>
<tr>
<td>CC-2</td>
<td>434033</td>
<td>0</td>
<td>114.783 Mb</td>
<td>3:06.0</td>
</tr>
<tr>
<td>CC-3</td>
<td>310</td>
<td>1</td>
<td>353.759 Mb</td>
<td>0:0.7</td>
</tr>
<tr>
<td>CC-4</td>
<td>434033</td>
<td>0</td>
<td>114.783 Mb</td>
<td>3:06.0</td>
</tr>
<tr>
<td>AW-1a</td>
<td>3071518</td>
<td>0</td>
<td>539.769 Mb</td>
<td>21:22.1</td>
</tr>
<tr>
<td>AW-1b</td>
<td>3057025</td>
<td>0</td>
<td>558.508 Mb</td>
<td>22:45.4</td>
</tr>
<tr>
<td>AW-2</td>
<td>3338868</td>
<td>0</td>
<td>967.955 Mb</td>
<td>39:22.2</td>
</tr>
<tr>
<td>AW-3</td>
<td>4183223</td>
<td>0</td>
<td>925.049 Mb</td>
<td>38:57.6</td>
</tr>
<tr>
<td>DoS</td>
<td>123</td>
<td>1</td>
<td>33.759 Mb</td>
<td>0:0.1</td>
</tr>
</tbody>
</table>

(now the runtime is given as minutes:seconds)

+ concurrency control & awareness aspects of the TT protocol augmented with a publish/subscribe notification service well designed!

− ‘superuser’ required to force a user to ever return a checked out file to the vault!
Publications

ter Beek-Massink-Latella-Gnesi-Forghieri-Sebastianis:

“A Case Study on the Automated Verification of Groupware Protocols”
(accepted for the Experience Reports Track of ICSE’05—the 27th International Conference on Software Engineering, ACM)

“Model Checking Publish/Subscribe Notification for thinkteam”
(FMICS’04—9th International Workshop on Formal Methods for Industrial Critical Systems, ENTCS, Elsevier)

“Automated Verification of Groupware Protocols”

used experience from ter Beek-Massink-Latella-Gnesi:

“Model Checking Groupware Protocols”
Conclusions

- case study on formalisation & verification of concurrency control & distributed notification aspects of groupware protocol underlying TT

- show feasibility & usefulness of model checking when verifying groupware protocols in general

- among first successful applications of exhaustive model checking to verification of publish/subscribe notification in a groupware setting

- think3 intends to use specification as basis for planned implementation of such services in TT

- think3 expressed interest in acquiring the skills to apply automated verification to the (groupware) protocols that underlie their software
Future Work

• numFiles > 1 in specification of TT protocol

• abandon file access based on \textit{retrial} principle (i.e. handshake instead of buffered channels)

⇒ initial verifications show feasibility!

• extend publish/subscribe notification service so that user who checks out a file is informed automatically of existing outstanding copies

• abandon assumption “no message is ever lost” (e.g. tag messages or send redundant copies)

• perform qualitative & quantitative verification (e.g. stochastic process algebras & automata)

⇒ first attempt (submitted) shows feasibility!

• apply this acquired knowledge & experience to other (groupware) protocols!