

Interval Temporal Logic

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[HTML version of the ITL home page](#)

Abstract

Interval Temporal Logic (ITL) is a flexible notation for both propositional and first-order reasoning about periods of time found in descriptions of hardware and software systems. Unlike most temporal logics, ITL can handle both sequential and parallel composition and offers powerful and extensible specification and proof techniques for reasoning about properties involving safety, liveness and projected time [126]. Timing constraints are expressible and furthermore most imperative programming constructs can be viewed as formulas in a slightly modified version of ITL [117]. Tempura provides an executable framework for developing and experimenting with suitable ITL specifications. In addition, ITL and its mature executable subset Tempura [149] have been extensively used to specify the properties of real-time systems where the primitive circuits can directly be represented by a set of simple temporal formulae. In addition, various researchers have applied Tempura to hardware simulation and other areas where timing is important.

1 Syntax

The key notion of ITL is an *interval*. An interval σ is considered to be a (in)finite sequence of states $\sigma_0, \sigma_1 \dots$, where a state σ_i is a mapping from the set of variables Var to the set of values Val . The length $|\sigma|$ of an interval $\sigma_0 \dots \sigma_n$ is equal to n , one less than the number of states in the interval (this has always been a convention in ITL), i.e., a one state interval has length 0.

The syntax of ITL is defined in Table 1 where

z is an integer value,

a is a static integer variable (doesn't change within an interval),

A is a state integer variable (can change within an interval),

v a static or state integer variable,

g is a integer function symbol,

q is a static Boolean variable (doesn't change within an interval),

Q is a state Boolean variable (can change within an interval),

h is a predicate symbol.

Table 1: Syntax of ITL

<i>Expressions</i>	
$e ::=$	$z \mid a \mid A \mid g(e_1, \dots, e_n) \mid \circ A \mid \text{fin } A$
<i>Formulae</i>	
$f ::=$	$\text{true} \mid q \mid Q \mid h(e_1, \dots, e_n) \mid \neg f \mid f_1 \wedge f_2 \mid \forall v \cdot f \mid$ $\text{skip} \mid f_1 ; f_2 \mid f^*$

2 Semantics

The informal semantics of the most interesting constructs are as follows:

- $\circ A$: if interval is non-empty then the value of A in the next state of that interval else an arbitrary value.
- $\text{fin } A$: if interval is finite then the value of A in the last state of that interval else an arbitrary value.
- skip unit interval (length 1).
- $f_1 ; f_2$ holds if the interval can be decomposed (“chopped”) into a prefix and suffix interval, such that f_1 holds over the prefix and f_2 over the suffix, or if the interval is infinite and f_1 holds for that interval.
- f^* holds if the interval is decomposable into a finite number of intervals such that for each of them f holds, or the interval is infinite and can be decomposed into an infinite number of finite intervals for which f holds.

Let $\llbracket \dots \rrbracket^e$ be the “meaning” (semantic) function from $Expressions \times (\Sigma^+ \cup \Sigma^\omega)$ to Val and let $\llbracket \dots \rrbracket$ be the “meaning” function from $Formulae \times (\Sigma^+ \cup \Sigma^\omega)$ to $Bool$ (set of Boolean values, $\{\text{tt}, \text{ff}\}$) and let $\sigma = \sigma_0 \sigma_1 \dots$ be an interval. We write $\sigma \sim_v \sigma'$ if the intervals σ and σ' are identical with the possible exception of their mappings for the variable v . The formal semantics is listed in Table 2:

3 Derived Constructs

Frequently used derived constructs are listed in table 3–6.

4 Propositional proof system

In table 7 we list the propositional axioms and rules for ITL.

Table 2: Semantics of ITL

$\llbracket z \rrbracket_\sigma^e$	=	\hat{z}
$\llbracket a \rrbracket_\sigma^e$	=	$\sigma_0(a)$ and for all $0 < i \leq \sigma $, $\sigma_i(a) = \sigma_0(a)$
$\llbracket A \rrbracket_\sigma^e$	=	$\sigma_0(A)$
$\llbracket g(e_1, \dots, e_n) \rrbracket_\sigma^e$	=	$\hat{g}(\llbracket e_1 \rrbracket_\sigma^e, \dots, \llbracket e_n \rrbracket_\sigma^e)$
$\llbracket \bigcirc A \rrbracket_\sigma^e$	=	$\begin{cases} \sigma_1(A) & \text{if } \sigma > 0 \\ \text{choose-any-from}(Val) & \text{otherwise} \end{cases}$
$\llbracket \text{fin } A \rrbracket_\sigma^e$	=	$\begin{cases} \sigma_{ \sigma }(A) & \text{if } \sigma \text{ is finite} \\ \text{choose-any-from}(Val) & \text{otherwise} \end{cases}$
$\llbracket \text{true} \rrbracket_\sigma$	=	tt
$\llbracket q \rrbracket_\sigma$	=	$\sigma_0(q)$ and for all $0 < i \leq \sigma $, $\sigma_i(q) = \sigma_0(q)$
$\llbracket Q \rrbracket_\sigma$	=	$\sigma_0(Q)$
$\llbracket h(e_1, \dots, e_n) \rrbracket_\sigma = \text{tt}$	iff	$\hat{h}(\llbracket e_1 \rrbracket_\sigma^e, \dots, \llbracket e_n \rrbracket_\sigma^e)$
$\llbracket \neg f \rrbracket_\sigma = \text{tt}$	iff	not ($\llbracket f \rrbracket_\sigma = \text{tt}$)
$\llbracket f_1 \wedge f_2 \rrbracket_\sigma = \text{tt}$	iff	($\llbracket f_1 \rrbracket_\sigma = \text{tt}$) and ($\llbracket f_2 \rrbracket_\sigma = \text{tt}$)
$\llbracket \text{skip} \rrbracket_\sigma = \text{tt}$	iff	$ \sigma = 1$
$\llbracket \forall v \cdot f \rrbracket = \text{tt}$	iff	(for all σ' s.t. $\sigma \sim_v \sigma'$, $\llbracket f \rrbracket_{\sigma'} = \text{tt}$)
$\llbracket f_1 ; f_2 \rrbracket_\sigma = \text{tt}$	iff	(exists k , s.t. $\llbracket f_1 \rrbracket_{\sigma_0 \dots \sigma_k} = \text{tt}$ and $\llbracket f_2 \rrbracket_{\sigma_k \dots \sigma_{ \sigma }} = \text{tt}$) or (σ is infinite and $\llbracket f_1 \rrbracket_\sigma = \text{tt}$)
$\llbracket f^* \rrbracket = \text{tt}$	iff	
if σ is finite then		(exist l_0, \dots, l_n s.t. $l_0 = 0$ and $l_n = \sigma $ and for all $0 \leq i < n$, $l_i \leq l_{i+1}$ and $\llbracket f \rrbracket_{\sigma_{l_i} \dots \sigma_{l_{i+1}}} = \text{tt}$)
else		(exist l_0, \dots, l_n s.t. $l_0 = 0$ and $\llbracket f \rrbracket_{\sigma_{l_n} \dots \sigma_{ \sigma }} = \text{tt}$ and for all $0 \leq i < n$, $l_i \leq l_{i+1}$ and $\llbracket f \rrbracket_{\sigma_{l_i} \dots \sigma_{l_{i+1}}} = \text{tt}$)
		or (exist an infinite number of l_i s.t. $l_0 = 0$ and for all $0 \leq i$, $l_i \leq l_{i+1}$ and $\llbracket f \rrbracket_{\sigma_{l_i} \dots \sigma_{l_{i+1}}} = \text{tt}$)

Table 3: Frequently used non-temporal derived constructs

false	$\hat{=}$	$\neg \text{true}$	false value
$f_1 \vee f_2$	$\hat{=}$	$\neg(\neg f_1 \wedge \neg f_2)$	or
$f_1 \supset f_2$	$\hat{=}$	$\neg f_1 \vee f_2$	implies
$f_1 \equiv f_2$	$\hat{=}$	$(f_1 \supset f_2) \wedge (f_2 \supset f_1)$	equivalent
$\exists v \cdot f$	$\hat{=}$	$\neg \forall v \cdot \neg f$	exists

Table 4: Frequently used temporal derived constructs

$\circ f$	$\hat{=}$	$\text{skip} ; f$	next
more	$\hat{=}$	$\circ \text{true}$	non-empty interval
empty	$\hat{=}$	$\neg \text{more}$	empty interval
inf	$\hat{=}$	$\text{true} ; \text{false}$	infinite interval
isinf(f)	$\hat{=}$	$\text{inf} \wedge f$	is infinite
finite	$\hat{=}$	$\neg \text{inf}$	finite interval
isfin(f)	$\hat{=}$	$\text{finite} \wedge f$	is finite
fmore	$\hat{=}$	$\text{more} \wedge \text{finite}$	non-empty finite interval
$\diamond f$	$\hat{=}$	$\text{finite} ; f$	sometimes
$\square f$	$\hat{=}$	$\neg \diamond \neg f$	always
$\textcircled{w} f$	$\hat{=}$	$\neg \circ \neg f$	weak next
$\textcircled{i} f$	$\hat{=}$	$f ; \text{true}$	some initial subinterval
$\textcircled{I} f$	$\hat{=}$	$\neg(\textcircled{i} \neg f)$	all initial subintervals
$\textcircled{s} f$	$\hat{=}$	$\text{finite} ; f ; \text{true}$	some subinterval
$\textcircled{S} f$	$\hat{=}$	$\neg(\textcircled{s} \neg f)$	all subintervals

5 First order proof system

Some axioms for the first order case are shown in Table 8.

Let v refer to both static and state variables.

We denote by f_v^e that in formula f expression e is substituted for variable v .

Table 5: Frequently used concrete derived constructs

$\text{if } f_0 \text{ then } f_1 \text{ else } f_2$	$\hat{=}$	$(f_0 \wedge f_1) \vee (\neg f_0 \wedge f_2)$	if then else
$\text{if } f_0 \text{ then } f_1$	$\hat{=}$	$\text{if } f_0 \text{ then } f_1 \text{ else true}$	if then
$\text{fin } f$	$\hat{=}$	$\Box(\text{empty} \supset f)$	final state
$\text{sfin } f$	$\hat{=}$	$\neg(\text{fin } (\neg f))$	strong final state
$\text{halt } f$	$\hat{=}$	$\Box(\text{empty} \equiv f)$	terminate interval when
$\text{shalt } f$	$\hat{=}$	$\neg(\text{halt } (\neg f))$	strong terminate interval when
$\text{keep } f$	$\hat{=}$	$\Box(\text{skip} \supset f)$	all unit subintervals
$\text{keepnow } f$	$\hat{=}$	$\Diamond(\text{skip} \wedge f)$	initial unit subinterval
f^ω	$\hat{=}$	$\text{isinf } (\text{isfin } (f)^*)$	infinite chopstar
$fstar(f)$	$\hat{=}$	$\text{isfin } (\text{isfin } (f)^*) \vee$ $\text{isfin } (\text{isfin } (f)^*) ; \text{isinf } (f)$	finite chopstar
$\text{while } f_0 \text{ do } f_1$	$\hat{=}$	$(f_0 \wedge f_1)^* \wedge \text{fin } \neg f_0$	while loop
$\text{repeat } f_0 \text{ until } f_1$	$\hat{=}$	$f_0 ; (\text{while } \neg f_1 \text{ do } f_0)$	repeat loop

Table 6: Frequently used derived constructs related to expressions

$A := exp$	$\hat{=}$	$\circ A = exp$	assignment
$A \approx exp$	$\hat{=}$	$\Box(A = exp)$	equal in interval
$A \leftarrow exp$	$\hat{=}$	$\text{finite} \wedge (\text{fin } A) = exp$	temporal assignment
$A \text{ gets } exp$	$\hat{=}$	$\text{keep } (A \leftarrow exp)$	gets
$\text{stable } A$	$\hat{=}$	$A \text{ gets } A$	stability
$\text{padded } A$	$\hat{=}$	$(\text{stable } (A) ; \text{skip}) \vee \text{empty}$	padded expression
$A \leftarrow\sim exp$	$\hat{=}$	$(A \leftarrow exp) \wedge \text{padded } A$	padded temporal assignment
$\text{goodindex } A$	$\hat{=}$	$\text{keep } (A \leftarrow A \vee A \leftarrow A + 1)$	increasing index
$\text{intlen } (exp)$	$\hat{=}$	$\exists I \cdot (I = 0) \wedge (I \text{ gets } I + 1) \wedge (I \leftarrow exp)$	interval length

Table 7: Propositional Axioms and Rules for ITL.

ChopAssoc	$\vdash (f_0; f_1); f_2 \equiv f_0; (f_1; f_2)$
OrChopImp	$\vdash (f_0 \vee f_1); f_2 \supset (f_0; f_2) \vee (f_1; f_2)$
ChopOrImp	$\vdash f_0; (f_1 \vee f_2) \supset (f_0; f_1) \vee (f_0; f_2)$
EmptyChop	$\vdash \text{empty}; f_1 \equiv f_1$
ChopEmpty	$\vdash f_1; \text{empty} \equiv f_1$
BiBoxChopImpChop	$\vdash \boxplus(f_0 \supset f_1) \wedge \boxminus(f_2 \supset f_3) \supset (f_0; f_2) \supset (f_1; f_3)$
StateImpBi	$\vdash p \supset \boxplus p$
NextImpNotNextNot	$\vdash \bigcirc f_0 \supset \neg \bigcirc \neg f_0$
KeepnowImpNotKeepnowNot	$\vdash \text{keepnow}(f_0) \supset \neg \text{keepnow}(\neg f_0)$
BoxInduct	$\vdash f_0 \wedge \boxminus(f_0 \supset \boxplus f_0) \supset \boxminus f_0$
InfChop	$\vdash (f_0 \wedge \text{inf}); f_1 \equiv (f_0 \wedge \text{inf})$
ChopStarEqv	$\vdash f_0^* \equiv (\text{empty} \vee ((f_0 \wedge \text{more}); f_0^*))$
ChopstarInduct	$\vdash (\text{inf} \wedge f_0 \wedge \boxminus(f_0 \supset (f_1 \wedge \text{fmore}); f_0)) \supset f_1^*$
MP	$\vdash f_0 \supset f_1, \vdash f_0 \Rightarrow \vdash f_1$
BoxGen	$\vdash f_0 \Rightarrow \vdash \boxminus f_0$
BiGen	$\vdash f_0 \Rightarrow \vdash \boxplus f_0$

Table 8: Some First Order Axioms and Rules for ITL.

ForallSub	$\vdash \forall v \cdot f \supset f_v^e,$ where the expression e has the same data and temporal type as the variable v and is free for v in f .
ForallImplies	$\vdash \forall v \cdot (f_1 \supset f_2) \supset (f_1 \supset \forall v \cdot f_2),$ where v doesn't occur freely in f_1 .
SubstAxiom	$\vdash \boxminus(A = B) \supset f \equiv f_A^B.$
StaticWeakNext	$\vdash w \supset \boxplus w,$ where w only contains static variables.
ExistsChopRight	$\vdash \exists v \cdot (f_1; f_2) \supset (\exists v \cdot f_1); f_2,$ where v doesn't occur freely in f_2 .
ExistsChopLeft	$\vdash \exists v \cdot (f_1; f_2) \supset f_1; (\exists v \cdot f_2),$ where v doesn't occur freely in f_1 .
ForallGen	$\vdash f \Rightarrow \vdash \forall v \cdot f,$ for any variable v .

6 Tools

6.1 (Ana)Tempura

Tempura, the C-Tempura interpreter version 2.7 developed originally by Roger Hale and now maintained by Antonio Cau and Ben Moszkowski, is an interpreter for executable Interval Temporal Logic formulae. The first Tempura interpreter was programmed in Prolog by Ben Moszkowski, and was operational around December 2, 1983. Subsequently he rewrote the interpreter in Lisp (mid Mar, 1984), and in late 1984 modified the program to handle a two-level memory and multi-pass scanning. The C-Tempura interpreter was written in early 1985 by Roger Hale at Cambridge University.

AnaTempura, which is built upon C-Tempura, is a tool for the runtime verification of systems using Interval Temporal Logic (ITL) and its executable subset Tempura. The runtime verification technique uses assertion points to check whether a system satisfies timing, safety or security properties expressed in ITL. The assertion points are inserted in the source code of the system and will generate a sequence of information (system states), like values of variables and timestamps of value change, while the system is running. Since an ITL property corresponds to a set of sequences of states (intervals), runtime verification is just checking whether the sequence generated by the system is a member of the set of sequences corresponding to the property we want to check. The Tempura interpreter is used to do this membership test.

Download Version:

- Version 3.3 (released 07/06/2016) [gzipped tar file](#) or [zip file](#).
 - The Tcl/Tk graphical user interface does not depend on Expect anymore.
 - The lexer/parser now throws an error on encountering a unknown character instead of silently discarding it.
 - The read-only State_number variable can be used in Tempura programs to determine the current state number.
 - The monitoring of C# programs does not need a Java wrapper anymore.
 - Support for monitoring of Java programs in the form of a jar file.
 - Support of time-stamps in the form of seconds and microseconds.
 - The GUI has now a different look/layout, history of commands window is gone, the most commonly used menu entries are now buttons and one interacts with Tempura using a shell-like interface.
 - Added template .anatempurarc .
 - Integers are now 64bits regardless of the machine architecture.
 - Windows binaries are compiled using the msys2-mingw32/64 system.
 - For Windows we have 32 bit (XP and beyond) and 64 bit (7 and beyond) Tempura/AnaTempura binaries.
 - Random numbers are now generated using xorshift128plus.

- Added support for monitoring Scala programs.
 - Added option `-stdio` to start `anatempura` in `cmdline` mode.
 - Various other bug fixes, see `ChangeLog` for more details.
- Version 3.2 (released 30/11/2015) [gzipped tar file](#) or [zip file](#).
 - Rewritten the Tempura output capture/processing routine.
 - Rewritten the external program data capture/processing routine.
 - New implementation of memory/framed variables, `existsf V : f`, is now used to indicate that `V` is memory/framed variable within `f`.
The previous syntax `mem(V)` is now deprecated.
 - Fix bugs in the implementation of `prev(L)` where `L` is a list.
 - Added Tempura binary for Arduino-Yun and Raspberry Pi, i.e., `tempura_mips_openwrt_linux` and `tempura_arm_linux_gnueabihf`.
 - Added elapsed time in the statistics output at the end of a run.
 - Added `plc` and `sql` injection detection examples.
 - Various other bug fixes see `ChangeLog` for more details.
- Version 3.1 (released 22/05/2015) [gzipped tar file](#) or [zip file](#).
 - Changed contact email address.
 - Added pre-compiled MacOSX binary.
 - Added `frame(V)` as alias for `mem(V)`
 - Fixed some bugs in implementation of `mem(V)`.
 - Fixed some bugs in the help command.
- Version 3.0 (released 04/07/2013) [gzipped tar file](#) or [zip file](#).
 - Dropped pre-compiled Solaris binary.
 - flex/bison based parser backward compatible with previous hard coded version but with stricter syntactic checks
 - changed from `cvs` to `svn` as version control system
 - improved syntax error messages
 - fixed memory leaks
 - tidy up format command
 - startup file `.anatempurarc` can also be in the current directory
 - use `kbs-0.4.4` to generate `anatempura` binaries
 - `anatempura` binaries are using `Tcl/Tk 8.6`
 - works again under Windows XP
 - program assertions can have any symbol except control characters and !
- Version 2.18 (released 01/11/2012): [gzipped tar file](#) or [zip file](#).

- Dropped tempura_macosx binary but added tempura_linux64 and anatempura_linux64 binaries.
 - fixed some small bugs
 - fixed memory leaks
 - added command 'winput' that will wait for input from a file instead of switching to the keyboard.
- Version 2.17 (released 04/10/2011): [gzipped tar file](#) or [zip file](#).
 - initial support for MACOSX
 - fixed gui bugs
 - fixed some tempura bugs
- Version 2.16 (released 08/12/2009): [gzipped tar file](#) or [zip file](#).
 - added floats. Floats have the form \$2.3e+10\$ in Tempura. For output: output(\$2.3\$) will be \$2.30000e+00\$, i.e., precision is 5 digits after the '.'. One can set this via the precision variable. With precision of 2 one gets \$2.30e+00\$. The format command can output floats in two forms: %f output will be of the form 2.33333, e output will be of the form 2.33333e+01. The following operations on floats are defined: unary, +, -; binary: +, -, div, mod, /, *, **, ceil, floor, sqrt, itof, exp, log, log10, sin, cos, tan, asin, acos, atan, atan2, sinh, cosh, tanh, fabs.
 - anatempura is now using the new Tile interface
 - when setting system variables with set, output both old and new values
 - Added 'frandom' and 'fRandom' for float random number between [0.0,1.0)
 - Added defaults command, X defaults 1 denotes when X is undefined then take as value for X the value 1.
 - Added prev(X) operator, the value of X in the previous state.
 - Added mem(X) operator, X is a 'memory' variable, i.e., when undefined take the value in the previous state.
 - Added #n history operator, used as option to exists when declaring a variable, it will keep a history of n previous values of a variable.
 - Added nprev(X,n) operator, nprev(X,3) for instance is an abbreviation of prev(prev(prev(X))).
 - When setting debug_level to 6 more usefull information is displayed like the state of a variable and reduction rule being applied.
 - Included tempura executables tempura_linux for Linux (compiled on Ubuntu 9.10), tempura_solaris for Solaris (compiled on Sparc Solaris 10u8), and tempura.exe for Windows (compiled on Windows XP SP3).

- Included anatempura executables anatempura_solaris, anatempura_linux and anatempura.exe. These were built using the Tclkit Kitgen build system (<http://wiki.tcl.tk/18146>). Now no need anymore to install tcl/tk and expect in order to run anatempura.
 - changed copyright license to GPLv3.0
- Version 2.15 (released 14/08/2008): [gzipped tar file](#) or [zip file](#).


```
*****2.15*****
```

 - introduced various node accessor macros so that if one changes the node structure we only have to change the macro.
 - if formula can't be reduced in the final state of the prefix of a chop then we will evaluate ((prefix and empty);true) and (suffix). This feature can be switched on/off with hopchop. The default of hopchop is true.
 - added integer overflow tests.
 - unified/cleaned up the various node data structures.
- Version 2.14 (released 29/11/2007): [gzipped tar file](#) or [zip file](#).


```
*****2.14*****
```

 - work around a recent misfeature of windows when started an external program.
 - added the io redirections, set infile="some file name", set outfile="some file name", where stdin and stdout can be used to redirect to standard keyboard and screen i/o.
 - added the infinite and randlen constructs for respectively an infinite interval and a random length interval (less or equal to max_randlen).
- Version 2.13 (released 28/08/2007): [gzipped tar file](#) or [zip file](#).


```
*****2.13*****
```

 - added reset in file menu to restart tempura.
 - open and reload now also load the file into Tempura.
 - added showstate Tempura command. This will display what is (un)defined in the current state.
 - changed contact email address to tempura@dmu.ac.uk
- Version 2.12 (released 04/05/2007): [gzipped tar file](#) or [zip file](#).


```
*****2.12*****
```

This version is the first version that compiles both under Windows and Unix/Linux type of machines. See Changelog for detailed news/changes.

How to run AnaTempura?

- Use the pre-compiled binary:

anatempera.exe: 32 bit binary and will run on Windows Xp, 7 and beyond, this will use tempura.exe in the current directory

anatempera-win64.exe: 64 bit binary and will run on Windows 7 and beyond, this will use tempura-win64.exe in the current directory

anatempera_linux: For 32bit Linux OS, this will use tempura_linux in the current directory

anatempera_linux64: For 64bit Linux OS, this will use tempura_linux64 in the current directory

anatempera_macosx: For MacOSX, this will use tempura_macosx in the current directory

- Use anatempera.tcl:

you need to install Tempura, and Tcl/Tk (at least 8.5). Get Tcl/Tk and from [Tcl/Tk site](#) or use the [ActiveTcl](#) package.

Tempura can be compiled using the Gnu C compiler under a Unix like operating system like Ubuntu, GNU Debian, etc. For Windows you can use the MSYS2/MinGW-32/64 system, see their [website](#) for downloading and installation. Install the MSYS2 system, and then, using pacman, install the mingw-w64-i686-toolchain for compiling 32bit binaries and the mingw-w64-x86_64-toolchain for compiling 64bit binaries.

Compile Tempura using the following commands

```
./configure  
make
```

For convenience the following pre-compiled Tempura binaries are included in the distribution:

32 bit Windows binary	tempura.exe,
64 bit Windows binary	tempura-win64.exe,
32 bit Linux binary	tempura_linux,
64 bit Linux binary	tempura_linux64,
MacOSX binary	tempura_macosx,
Arduino-Yun binary	tempura_mips_openwrt_linux,
Raspberry Pi binary	tempura_arm_linux_gnueabihf.

Contact: Email cau.researcher@gmail.com in case of problems.

Publications:

- Analysing C programs is discussed in:
[A Framework For Analysing The Effect of ‘Change’ In Legacy Code](#), S. Zhou, H. Zedan and A. Cau. In IEEE Proc. of ICSM’99, 1999.
- Analysing Verilog programs is discussed in:
[A logic-based Approach for Hardware/Software Co-design](#), H. Zedan and A. Cau. Digest of IEE event Hardware-Software Co-design, 8 Dec., 2000.
- A paper describing the run-time verification method used in AnaTempura:
[Run-time analysis of time-critical systems](#). S. Zhou and H. Zedan and A. Cau. Journal of System Architecture, 51(5):331-345, 2005.
- Slides of seminar talk about AnaTempura:
[AnaTempura](#), A. Cau, S. Zhou and H. Zedan.

Overview: Figure 1 shows an overview of AnaTempura.

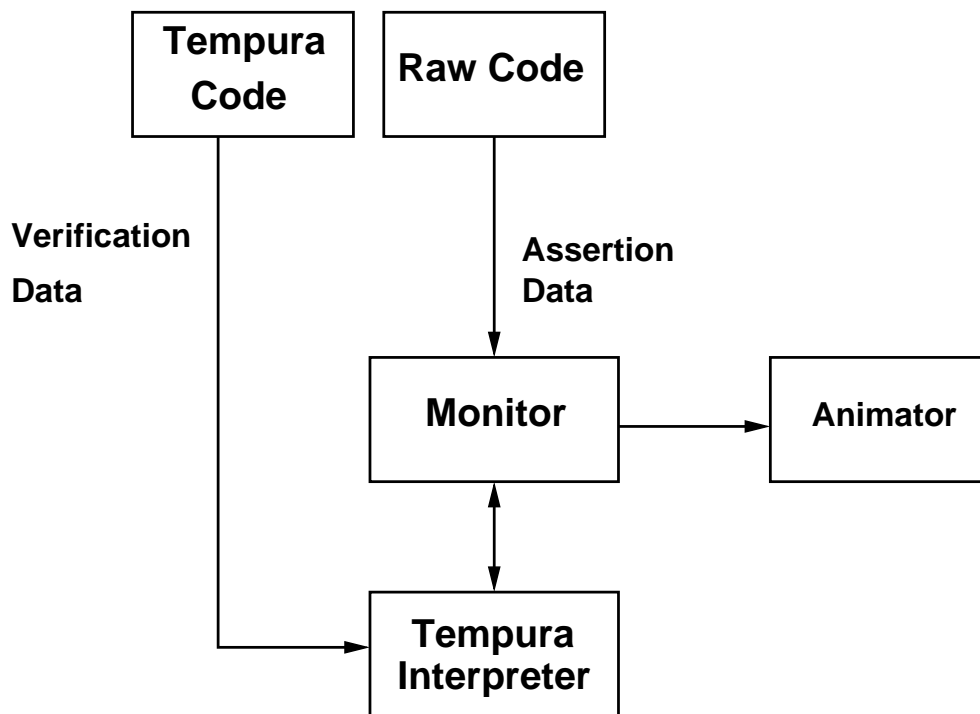


Figure 1: Overview of AnaTempura

Figure 2 shows the interface of AnaTempura.

Figure 3 shows a graphical snapshot of a simulation of the EP/3 microprocessor specified in Tempura.

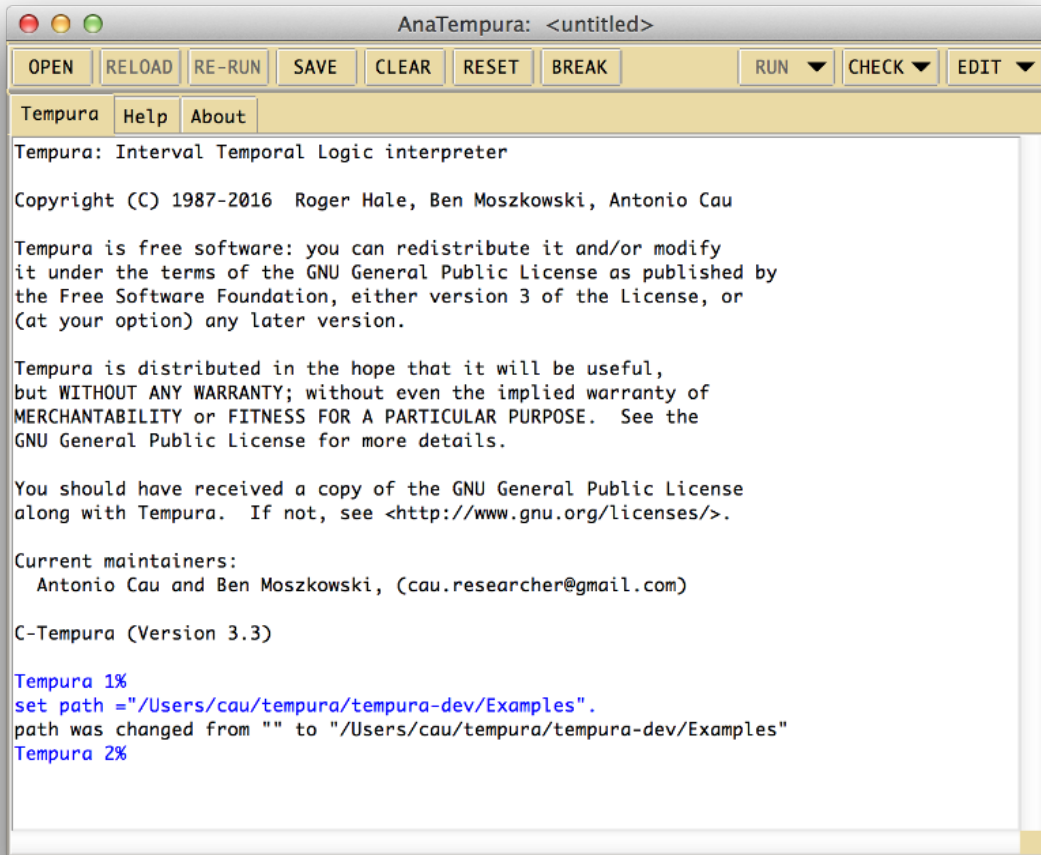


Figure 2: Interface of AnaTempura

6.2 ITL Theorem Prover based on Prover9

Prover9 is a resolution/paramodulation automated theorem prover for first-order and equational logic developed by William McCune.

We have given an algebraic axiom system for Propositional Interval Temporal Logic (PITL): **Interval Temporal Algebra**. The axiom system is a combination of a variant of Kleene algebra and Omega algebra plus axioms for linearity and confluence.

This algebraic axiom system for PITL has been encoded in Prover9. So we can use Prover9 to prove the validity of various PITL theorems. The Prover9 encoding of PITL plus examples of more than 300 PITL theorems are available for download as

- Version 1.8 (released 27/08/2009): [gzipped tar file](#).
- documentation updated to new semantics for

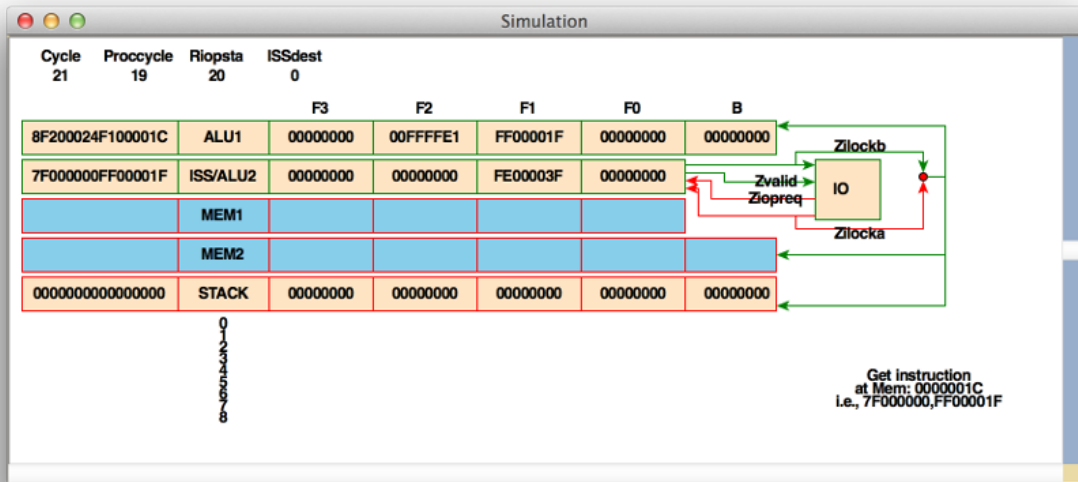


Figure 3: Graphical snapshot of simulation of the EP/3 microprocessor

chopstar and chop omega algebraic operators

- Version 1.7 (released 15/05/2009): [gzipped tar file](#).
 - updated documentation in doc, to use new ITL semantics
- Version 1.6 (released 12/12/2008): [gzipped tar file](#).
 - changed copyright license to GPLv3.0 and added the notice to all files
- Version 1.5 (first public release: 05/12/2008): [gzipped tar file](#).

The README in this tar file contains instructions how to use Prover9 for proving PITL theorems.

6.3 FLCheck: Fusion Logic decision Procedure

Fusion Logic augments conventional Propositional Temporal Logic (PTL) with the fusion operator. Note: the fusion-operator is basically a “chop” that does not have an explicit negation on the left hand (for right fusion logic) side (as fusion expression) or the right hand (for left fusion logic). The negation is implicit, i.e., the negation is a derived fusion expression operator. The expressiveness of Fusion Logic is the same as Propositional Interval Temporal Logic. The main differences concern computational complexity, naturalness

of expression for analytical purposes, and succinctness. Fusion Logic is closely related to Propositional Dynamic Logic (PDL).

We have implemented above [decision procedure for Fusion Logic](#) in [Tel/Tk](#) and the [CUDD](#) BDD library. The tool allows one to check the validity or satisfiability of a Fusion Logic formula. If a formula is not valid it will produce a counter example and if a formula is satisfiable it will produce an example model. [Figure 4](#) gives a screen dump of our tool which is available at

- [FLCHECK version 1.2 \(released 22/05/2015\)](#).

Main Changes:

- Added support for MacOSX.
- Added pre-compiled binary for MacOSX.

- [FLCHECK version 1.1 \(released 04/07/2013\)](#).

Main Changes:

- Drop support for Solaris Sparc.
- Added pre-compiled binaries for Windows (XP and 7) and Linux (Ubuntu 12.04, 32 and 64 bits).

- [FLCHECK version 1.0 \(released 23/01/2013\)](#).

Main Changes:

- Simplified ‘left always followed by’ operator.
- Added more examples.

- [FLCHECK version 0.9 \(released 21/02/2012\)](#).

Main Changes:

- Introduction of left and right Fusion Logic which makes the specification of access control policies much simpler
- Use of time reversal to rewrite left fusion logic formulae into right fusion logic formulae
- Enforcement of policies expressed in left Fusion Logic
- All examples come now with comments

- [FLCHECK version 0.8 \(released 26/03/2010\)](#).

Initial release.

Publications:

- Antonio Cau, Helge Janicke, and Ben Moszkowski. [Verification and enforcement of access control policies](#). Formal Methods in System Design, Springer, 2013.
- [A Note on Expressing Policy Rules in Fusion Logic](#), A. Cau. Technical report, STRL, De Montfort University.

```
FLCHECK: /Users/cau/serenity/acau-backup/perlDd/tclDd/cudd/example-policy-keys-I...
Output Help Input Reverse Reduce Gamma1 Gamma2 Gamma3
***Testing enforcer against input trace using time reversal.
first state
State 0:
A=0
KA=1
KB=1
first state
State 1:
A=1
KA=0
KB=1
first state
State 2:
enf_l [test_keys_enf_left]
```

Figure 4: FLCHECK fusion logic decision procedure

6.4 ITL Proof Checker based on PVS

PVS is an interactive environment, developed at SRI, for writing formal specifications and checking formal proofs. The specification language used in PVS is a strongly typed higher order logic. The powerful interactive theorem prover/proof checker of PVS has a large set of basic deductive steps and the facility to combine these steps into proof strategies.

PVS is implemented in Common Lisp –with ancillary functions provided in C, Tcl/TK and LaTeX– and uses GNU Emacs for its interface. PVS is freely available for IBM RS6000 machines as well as Sun Sparcs under license from SRI. See [PVS homepage](#) for more information.

- The [ITL library for PVS 4.0](#).
- The [ITL library for PVS 3.2](#).
- The [ITL library for PVS 2.4 patchlevel 1](#).
- The [ITL library for PVS 2.3](#).
- The [ITL library for PVS 2.2](#).
- The [ITL library for PVS 2.1 patchlevel 2.417](#).

Publications:

- [Technical report](#).

6.5 Automatic Verification of Interval Temporal Logic

[Shinji Kono](#) has developed an automatic theorem prover for propositional ITL (LITE). The implementation is in Prolog. Further information can be gathered at [Shinji Kono's Interval Temporal Logic page](#). Shinji Kono has also a Java version of LITE see [CVS repository of JavaLite](#).

7 Tempura Book

The book *Executing Temporal Logic Programs* by Dr. B. C. Moszkowski was originally published by Cambridge University Press in 1986. The publishers have kindly given the copyright back to the author. The [pdf version of the book](#) has now been made available.

8 ITL Related Publications

[Download BibTeX file](#)

8.1 Articles

- [1] Ben Moszkowski and Dimitar Guelev. “An application of temporal projection to interleaving concurrency”. In: *Formal Aspects of Computing* 29.4 (July 2017), pp. 705–750.
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