The Concurrency Workbench: *making CCS run*

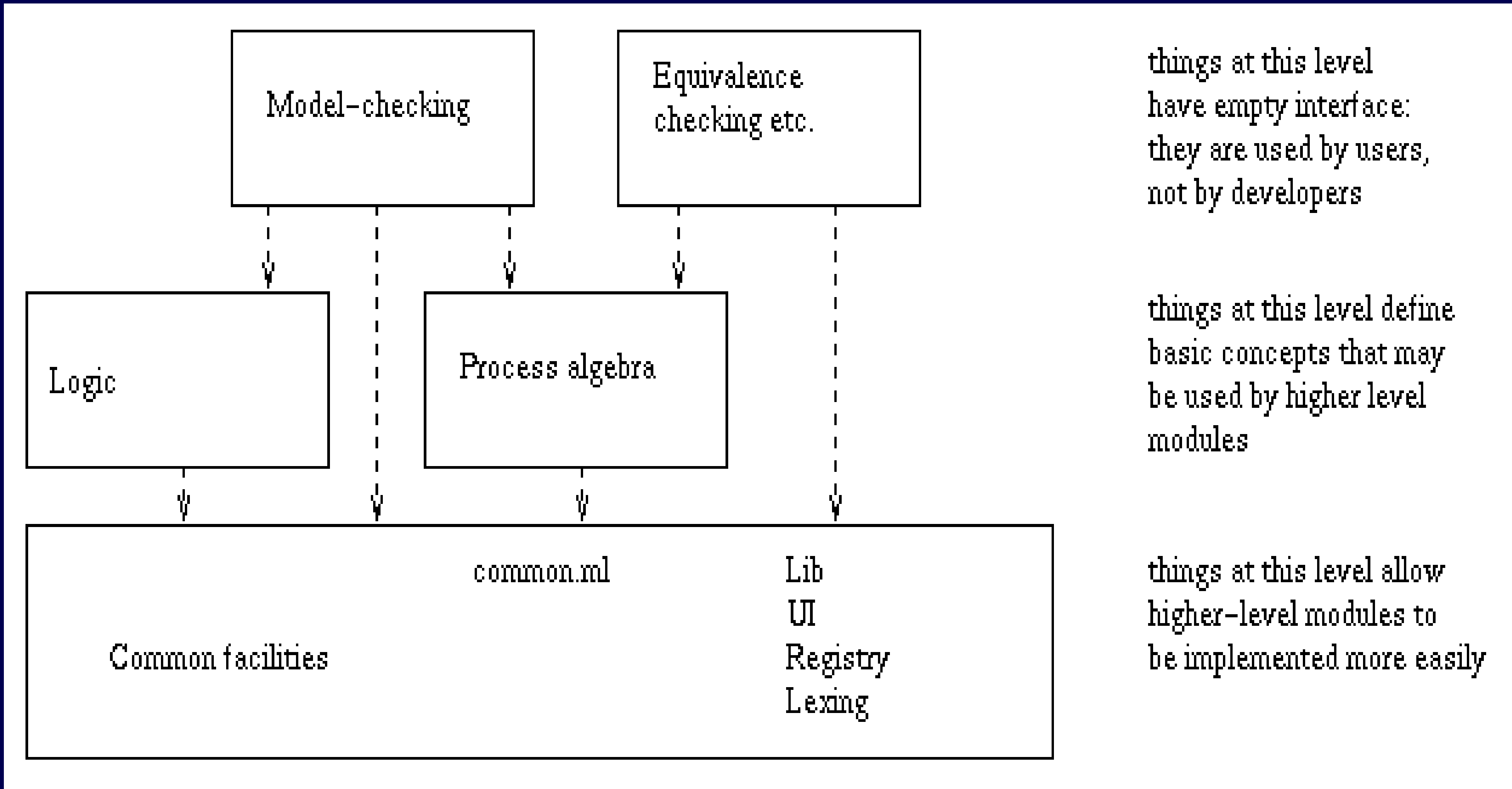
Featuring:
- CWB Edinburgh Version 7.1
- Emacs &
- daVinci 2.1

1. A word about tools
2. Calculus of Communicating Systems (CCS)
3. The modal μ-Calculus
4. Case study: Fairness is a problem
5. Theory for Practice?

A Short Timeline

'86	conceived from *theoretical*, educational and practical concerns
	used both in teaching and industry
	treatment for CCS, TCCS and SCCS
'94	$\approx$ 20,000 lines of SML code, $\approx$ 90 commands
	(this is when a systems- and software engineer was hired)
today	Version 7.1 available for Solaris and Linux
	about 800 KB SML source code
	interface: Emacs & daVinci

Structure of the CWB



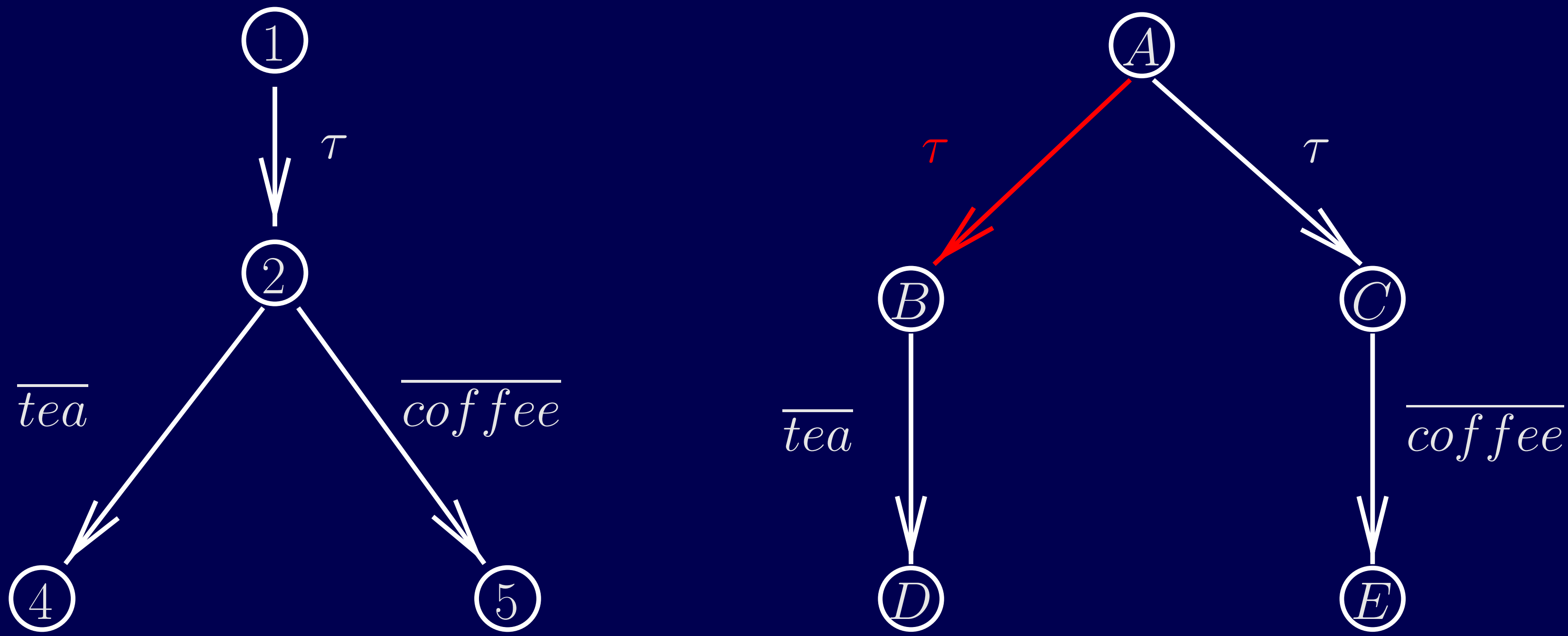
What can we do with the CWB?

- define agents
- simulate agents
- check equalities
- check properties from the modal μ-calculus

CCS in the Concurrency Workbench

AGENT	`A`	`0`	deadlock (nil)
		`a.A`	action prefix
		`tau.A`	silent prefix
		`A + A`	(weak) choice
		`A | A`	parallel composition
		`A \ S`	restriction: actions in `S` synchronized
		`(A)`	you can use brackets almost as you'd expect
SET	`S`	`{a,b,c,...}`	a collection of actions

Making Coffee



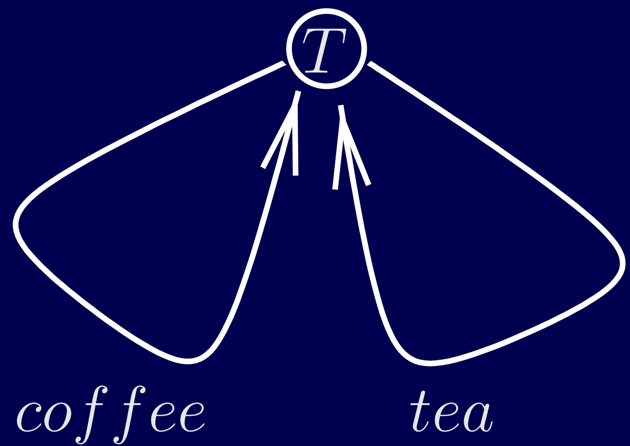
not bisimilar

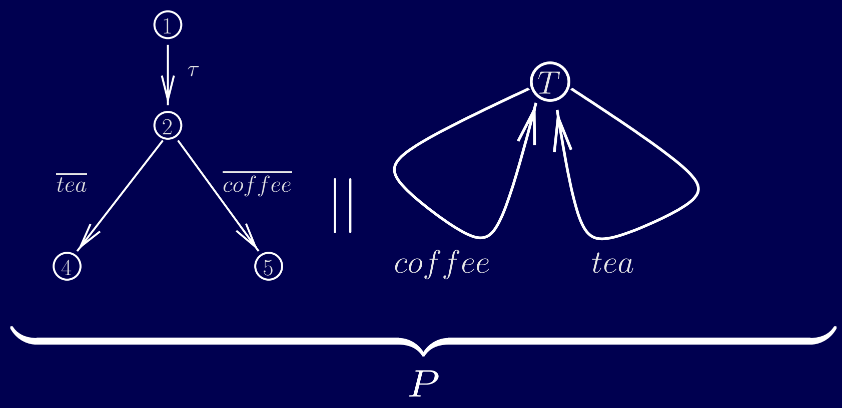
not weakly bisimilar

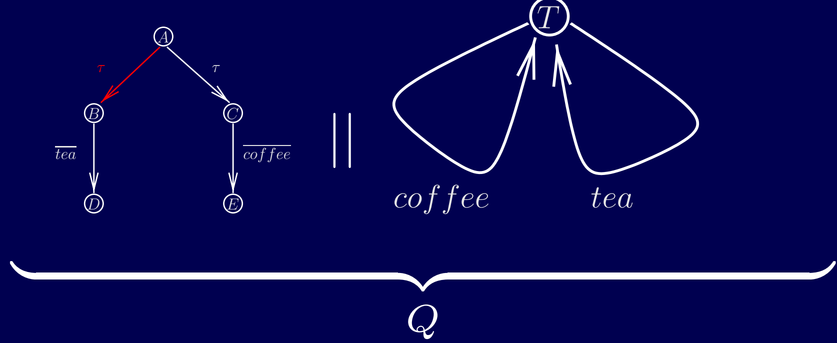
cannot match $A \xrightarrow{\tau} B$

Drinking Coffee

Add a consumer:



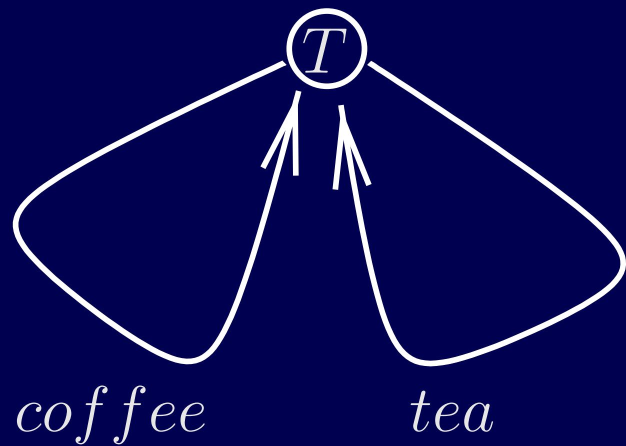


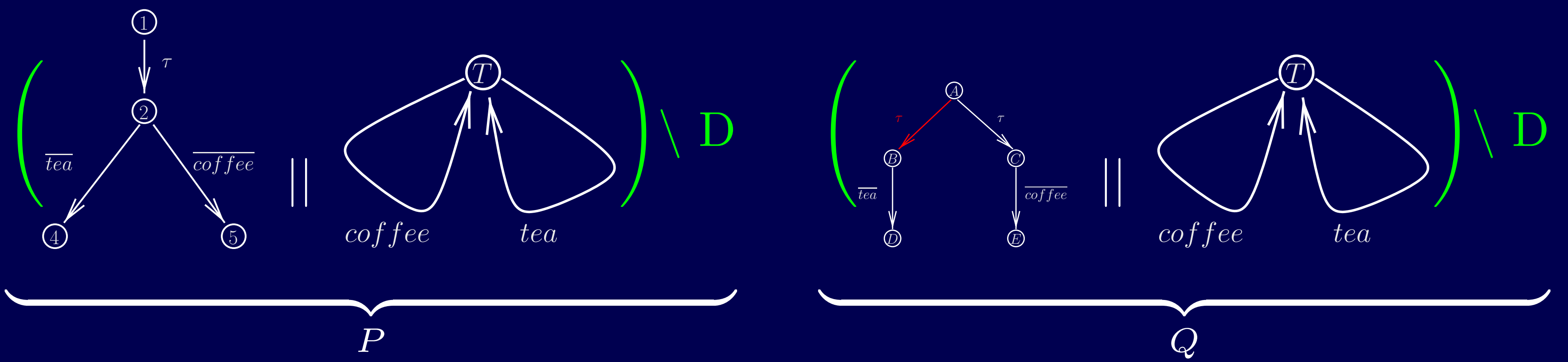


Now P and Q are even strongly bisimilar

Drinking Coffee

Add a consumer:





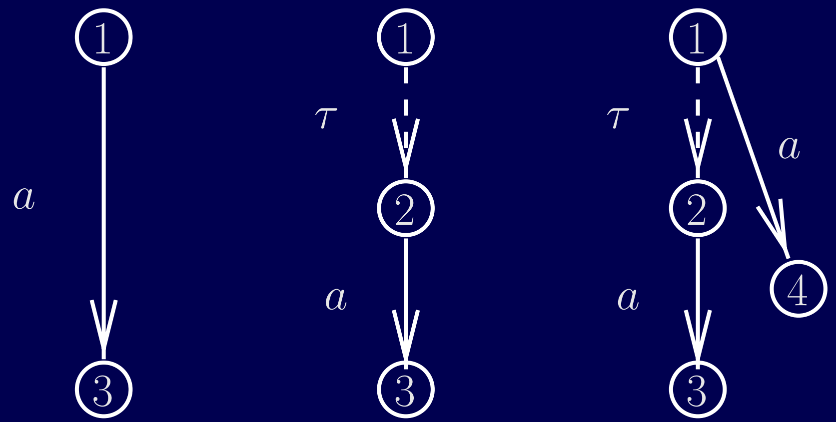
Now P and Q are even strongly bisimilar if we require them to synchronize on their actions:

$$D := \{tea, coffee\}$$

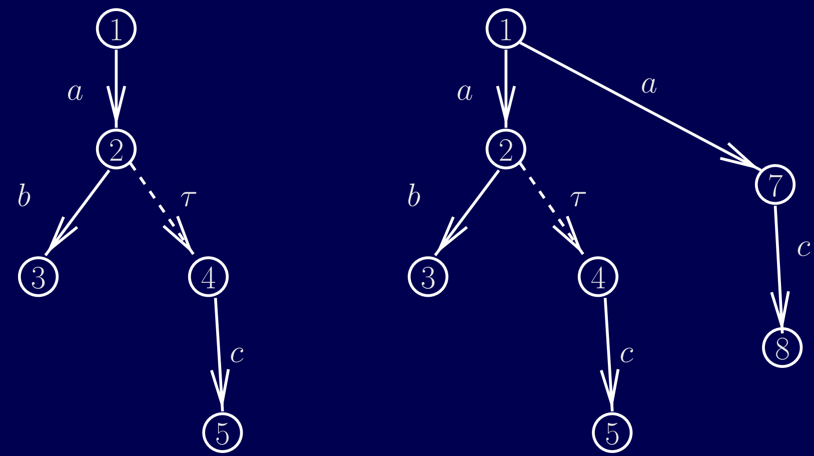
Reminder: Levels of Equivalence

$\sim$	`strongeq`	congruence :	$P \sim Q > P + R \sim Q + R$
			$P \mid\mid R \sim Q \mid\mid R$
$\approx$	`eq`	process congruence :	$P \approx Q > \alpha.P + R \approx \alpha.Q + R$
			$P \mid\mid R \approx Q \mid\mid R$
	`mayeq`	trace equivalence	P can produce trace α $\Leftrightarrow$
			Q can produce trace α

Additional (weak) Equalities

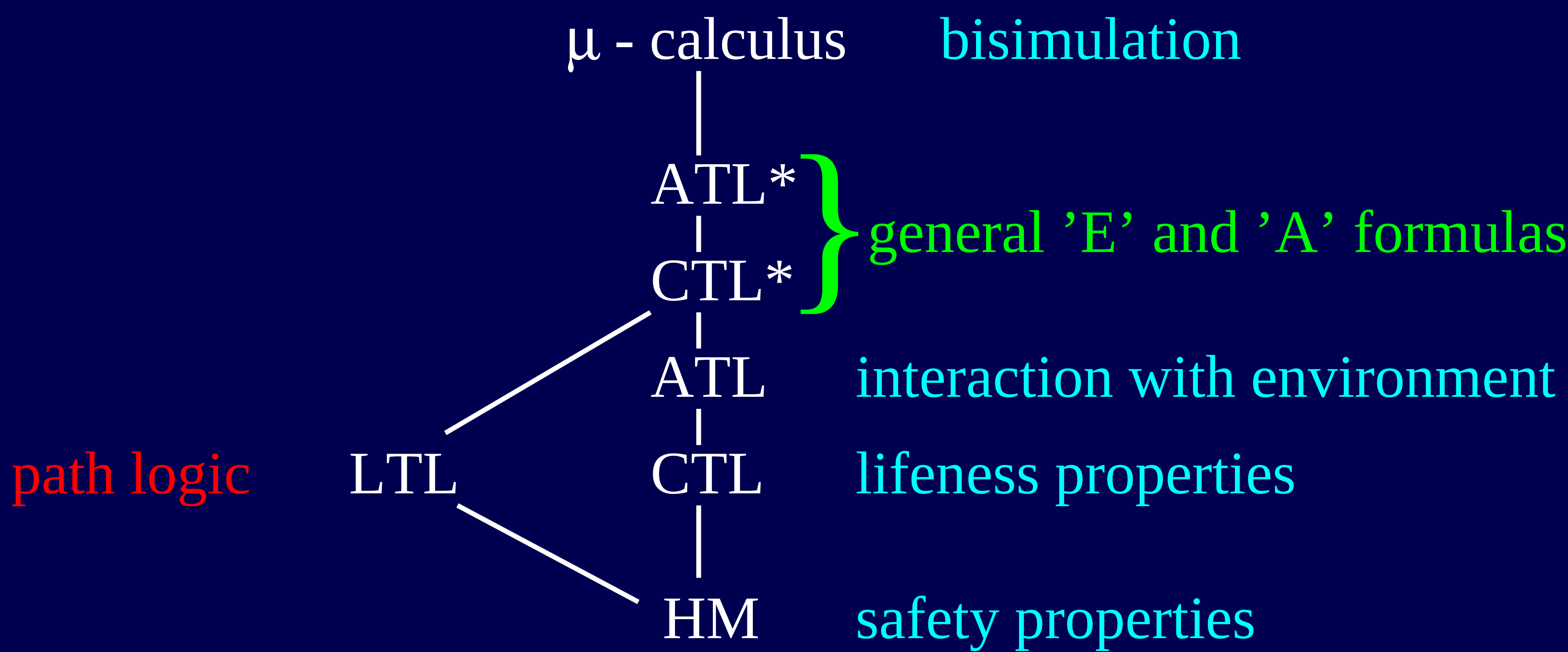


$$a \;\approx\; \tau.a \;\approx\; a + \tau.a$$



$$a.(b + \tau.c) \;\approx\; a.(b + \tau.c) + a.c$$

Temporal Logics



μ Calculus Syntax in CWB

PROP	P	T	true
		F	false
		~P	negation
		P & P	conjunction
		P | P	disjunction
		P => P	implication
		[a,...]P	strong necessity
		[-a,...]P	strong complement necessity
		[[a,...]]P	weak necessity
		$\langle a,\ldots\rangle$P	strong possibility
		$\langle\langle a,..\rangle\rangle$	weak possibility

Special non-labels

tau: unobservable action

- tau.a.0 $\models$ <tau><a>T
- tau.a.0 $\not\models$ <a>T
- tau.tau.a.0 $\not\models$ <tau><a>T
- tau.a.0 $\models$ <<tau>><a>T

Special non-labels

tau: unobservable action

- `tau.a.0` $\models$ `<tau><a>T`
- `tau.a.0` $\not\models$ `<a>T`
- `tau.tau.a.0` $\not\models$ `<tau><a>T`
- `tau.a.0` $\models$ ~~`<<tau>><a>T`~~ not allowed

eps: empty observation

- `tau.a.0` $\models$ `<<eps>><a>T`
- `a.0` $\models$ `<<eps>><a>T`
- `a.b.0` $\models$ `<-eps><b>T`

Fixpoint Operators

min(X.P)	least fixpoint temporal formula
max(X.P)	greatest fixpoint temporal formula

`max(Z.`φ` & [-]Z)`	`AG `φ	Invariant
`max(Z.[a]F & [-]Z)`	`AG [a]F`	Safety: Never a
`min(Z.<a>T | <->Z)`	`EF <a>T`	Eventually a
`min(Z.[-a]F | (<->T &[-]Z))`	`AF (<a>T&[-a]F)`	Inevitably a
`min(Z.Q | (P & <->T & [-]Z))`	`P Until Q`	strong until
`max(Z.Q | (P & [-]Z))`	`P Wuntil Q`	weak until
`max(Z.[a]min(Y.<->T & [-b]Y)&[-]Z`	`AG(a => AF<b>T)`	Response

What we have *not*:

- a notion of states or local propositions
- a global store
- an easy way to check, that a μ-formula and intuition coincide

Common Pitfalls

tau and eps

true: <<eps>> $\equiv$ <<-S>> $\equiv$ <tau>*

false: <<-eps>> $\equiv$ <<S>>

e.g. tau.a.0 $\models$ <<-eps>><a>T but tau.a.0 $\not\models$ <<S>><a>T

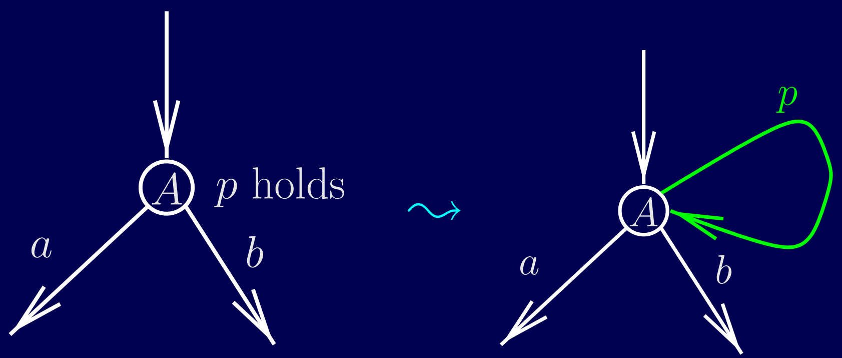
Modalities in fixed points

max(Z.φ & [-]Z) : φ allways

max(Z.φ & [S]Z) : φ in all paths excluding tau

S: set of all observable actions

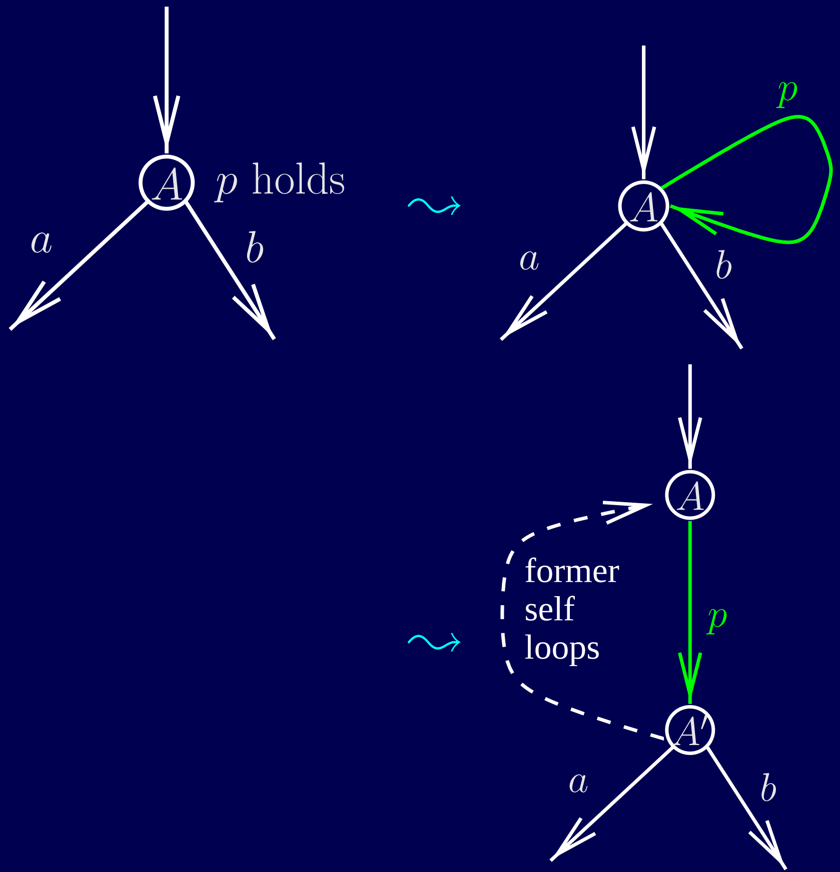
Living without Propositional Formulas



Problems:

- deadlock properties not preserved
- `AF` properties fail now

Living without Propositional Formulas



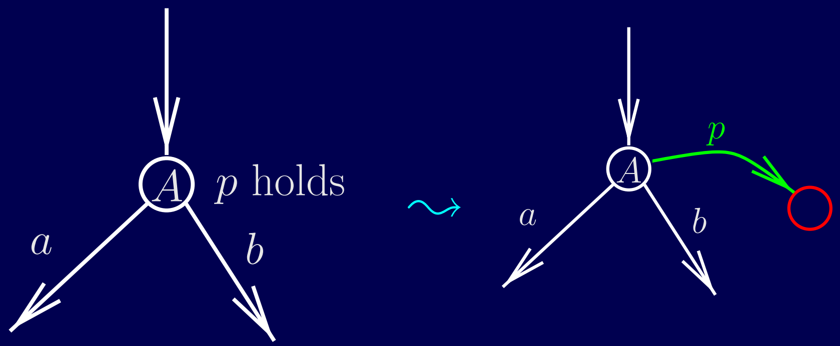
Problems:

- deadlock properties not preserved
- `AF` properties fail now

Problems:

- p must be unsynchronized
- we destroy one-step properties
- a, b do not stay enabled

Living without Propositional Formulas (2)



Problems:

- introduces deadlocks
- `AF` properties fail now

Thus: We can augment our model, to make states *observable*...

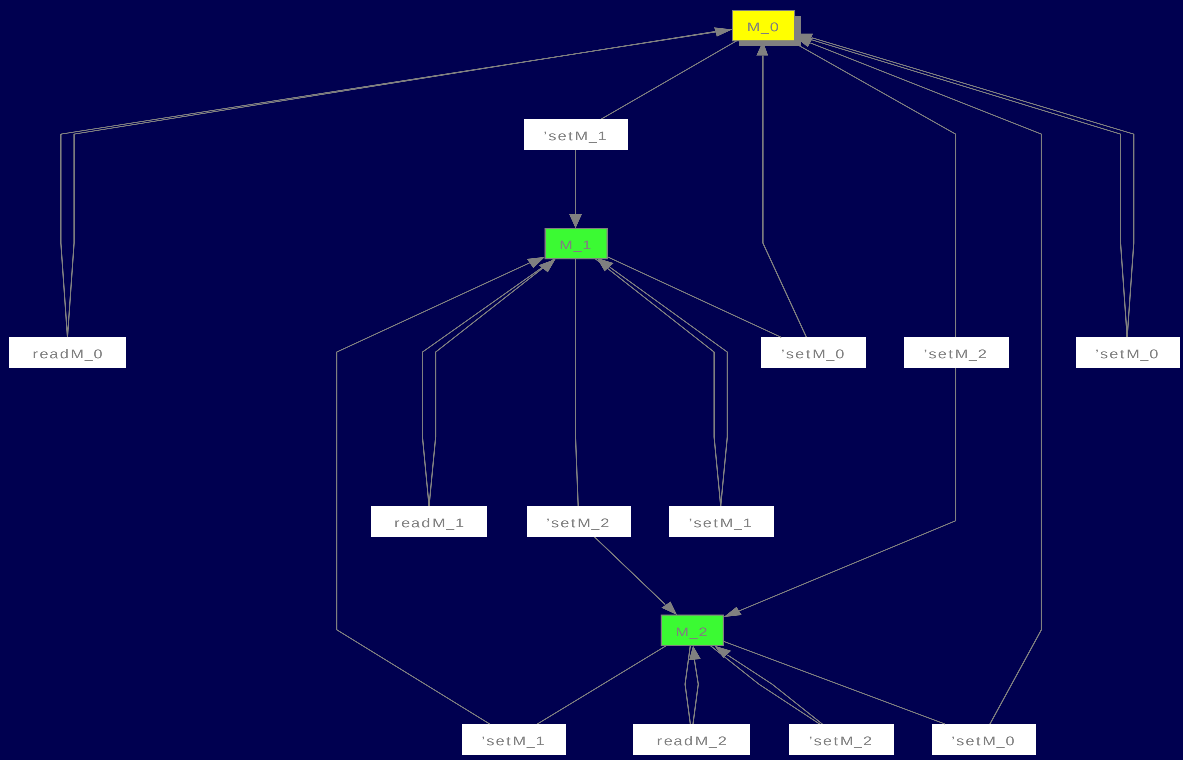
but we have to be careful not modify the behaviour!

Living without Memory

CWB does not allow a store as part of a systems state.

> We have to model it explicitly

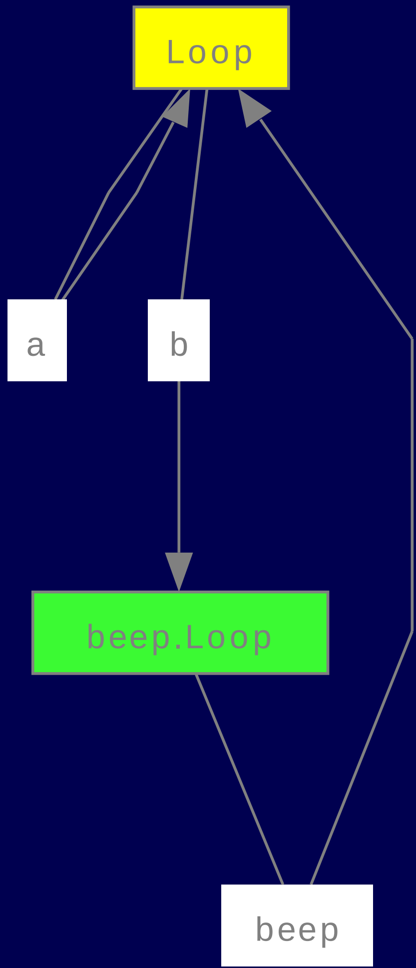
Variable `M` of type `int[0..2]`



Problems:

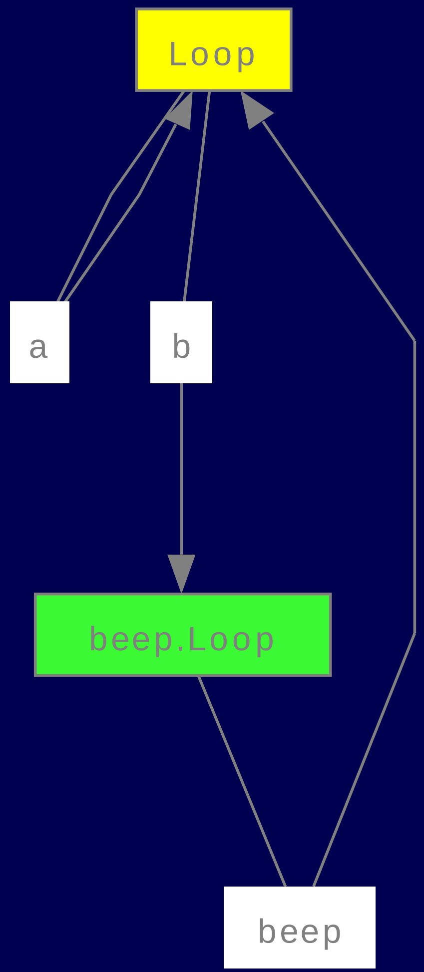
- Sequential Queries
- Tedious

Weak Fairness



Want:	exclude all runs $\Sigma^* a^\omega$
1. Attempt:	Always, b will eventually be taken
	$\nu\mathbf{X}.\mu\mathbf{Y}.(\langle\text{-}\rangle\mathbf{T} \wedge [-\mathbf{b}]\mathbf{Y}) \wedge [-]\mathbf{X}$
2. Attempt:	If a is taken ∞ often, then so is b
	$\mu\mathbf{X}.\nu\mathbf{Y}.(\langle a\rangle\mathbf{T} \vee \mathbf{X}) \wedge [-\mathbf{b}]\mathbf{Y}$

Weak Fairness



Want:	exclude all runs $\Sigma^* a^\omega$
1. Attempt:	Always, b will eventually be taken
	$\nu \mathbf{X}.\mu \mathbf{Y}.(\langle\text{-}\rangle \mathbf{T} \wedge [-\mathbf{b}]\mathbf{Y}) \wedge [-]\mathbf{X}$
2. Attempt:	If a is taken ∞ often, then so is b
	$\mu \mathbf{X}.\nu \mathbf{Y}.(\langle a\rangle \mathbf{T} \vee \mathbf{X}) \wedge [-\mathbf{b}]\mathbf{Y}$
Problem:	We can *express* fairness,
	but not add it as an *Assumption*

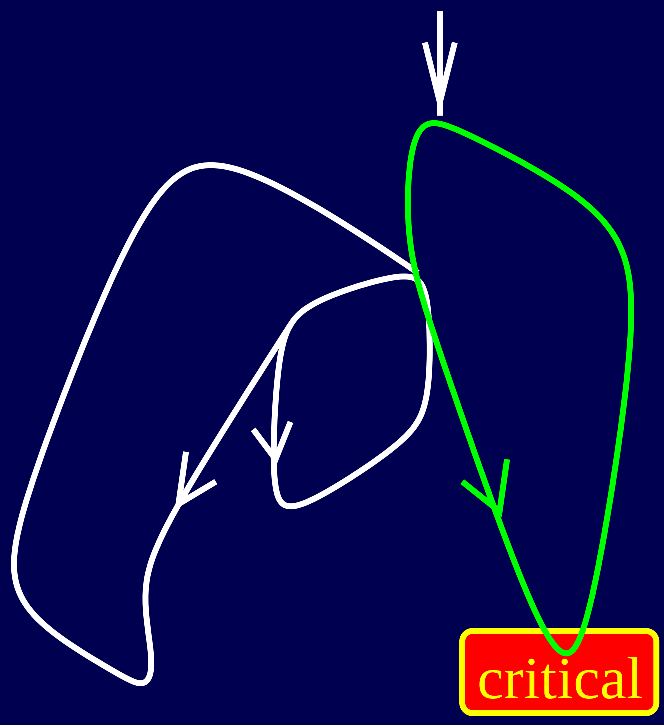
'inevitably, it will beep' is equivalent to false.
AND: our formulas are equivalent to false.

Dekker's Mutex Algorithm

```
**** Agent 1 ****
 while true
   b1 := true
   while b2 do
     if k = 2 then
       b1 := false
       while k = 2 skip;
       b1 := true
   <enter critical region>
   <exit critical region>
   k := 2
   b1 := false
```

Dekker's Mutex Algorithm

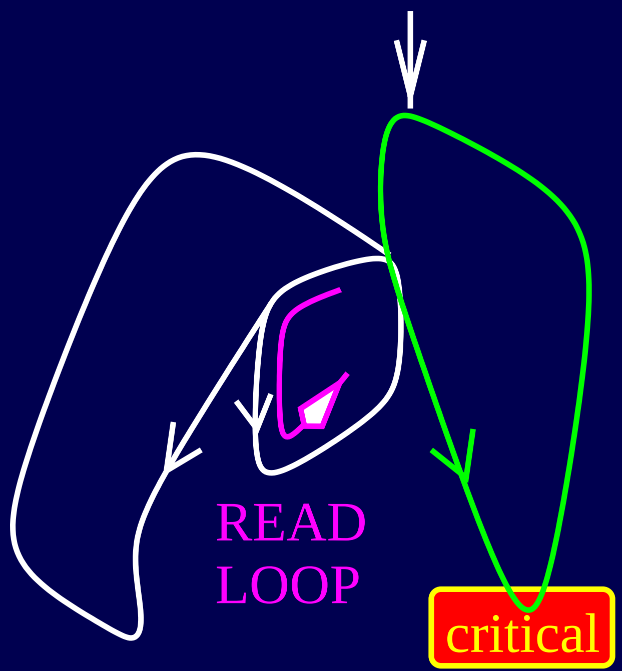
```
**** Agent 1 ****
 while true
   b1 := true
   while b2 do
     if k = 2 then
       b1 := false
       while k = 2 skip;
       b1 := true
   <enter critical region>
   <exit critical region>
   k := 2
   b1 := false
```



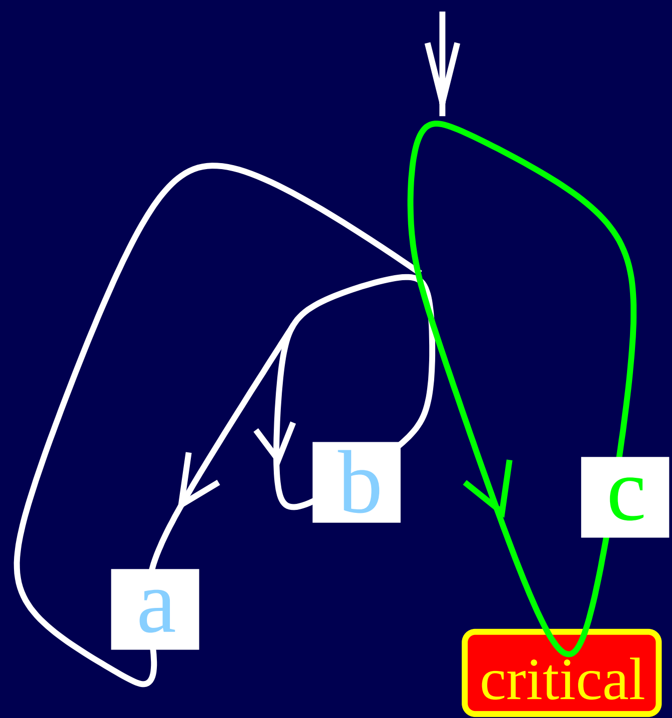
Want to prove:

Freedom from individual starvation

Problem: Read Loops



(Unfair) loops are possible.
> Freedom from individual starvation requires a fairness assumption



In order to incorporate a fairness assumption, we introduce additional observable actions **a,b,c**.

A Detour to (Starvation) Freedom

1. The system is deadlock-free:

$$\texttt{System} \models \nu Z.\texttt{<->T} \wedge \texttt{[-]}Z$$

2. It is impossible to reach fair loops:

$$\forall \text{actions } x : \quad \texttt{System} \not\models \mu Z.(\nu X.\texttt{[[-}x\texttt{]]F} \wedge \texttt{[[}x\texttt{]]}X) \vee \texttt{<->}Z$$

3. If actions x, y happen ∞ often, then c happens ∞ often :

$$\texttt{System} \models \nu Z.\mu X.(\texttt{[}x\texttt{]}(\nu Y.(\texttt{[}y\texttt{]}(\nu W.(X \wedge \texttt{[-}c\texttt{]}W))) \wedge \texttt{[-}c\texttt{]}Y) \wedge \texttt{[-]}Z)$$

strong fairness $\overset{1,2}{\leadsto}$ at least two actions are observed ∞ often

$\overset{3}{\leadsto}$ freedom of individual starvation

Is the CWB a Tool for Industry?

Motivations for using the CWB

- curiosity (see CCS 'work')
- verification (prove properties about your model)
- the attractive expressiveness of μ-calculus formulas
- experiments with own
  - process algebras
  - logics
  - modelchecking algorithms

Limitations

- SML implementation rather consumptive (time/memory)
- graphical viewer does not scale well

$\leadsto$ can be *overcome*... by investment of sufficient manpower

Why is it not used every day?

⋆ *interface* is a command-line

⋆ the *agent model* is unfamiliar to engineers

⋆ logic is *too difficult* to understand

How do Industrial Tools Look Like?

Industrial tools

- do things that are *conceptually* simple
- ... but large and complex
- are (relatively) easy to understand and to operate
- have to be capable of dealing with **large instances**

... and they have nice user interfaces(!)

methods that are difficult to learn

technologies that require experts

hands off: non-proven technologies

Tools in Practice

μ − calculus CWB[−NC], Theorem provers

ATL*
CTL* } no specialized tools

Waterline

ATL Mocha

SPIN LTL CTL SMV

HM reachability (e.g visualState)

Incomplete Methods: Simulation, (automated) Testing

Invitation: Dig Deeper

The user manual The Edingburgh Concurrency Workbench (Version 7.1)

Colin Stirling's Article Bisimulation, Model Checking and other Games

The tool page of Kim's course `http://www.brics.dk/~omoeller/v01/`

Find these slides at
`http://www.brics.dk/~omoeller/v01/cwb.pdf`