This box should lie exactly on top
of the Camtasia video area frame.

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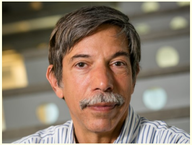
VERIFYING HYPERPROPERTIES with TLA

Leslie Lamport

Fred B. Schneider



[pause] What is a hyperproperty? ©

Hyperproperties

Ⓒ An ordinary property is a predicate that's true or false of a single execution of a system. Ⓒ

For example, the property that every request receives a response.Ⓒ

Verifying Ⓒ that a system satisfies a property Ⓒ
means showing that every execution of the system satisfies the property.Ⓒ

0 min 25 sec

Hyperproperties

Ordinary property: True or false of an execution.

© An ordinary property is a predicate that's true or false of a single execution of a system. ©

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$S \models P$

system — property

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Verification:

$S \models P$ means $\sigma \models P$

system — property; any execution of S — property

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Hyperproperty: True or false of a set of executions.

A hyperproperty is a predicate that's true or false on the set of executions of a system, not just on single executions.©

Some security conditions are naturally expressed as hyperproperties–for example©

Observational Determinism or OD. OD assumes that an execution is a ©
sequence of states, and a state © consists of two parts:©
a public state and a secret state. ©

0 min 54 sec

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(4,“*foo*”)

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public secret

a public state and a secret state. ©

OD requires that if any two executions © have the same initial public states, then they © always have the same public states. ©

This is an assertion about pairs of executions, not about a single execution. ©

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$$
\begin{array}{ccccccc}
\text{state}_1 & \rightarrow & \text{state}_2 & \rightarrow & \text{state}_3 & \rightarrow & \cdots \\
\uparrow & & & & & & \\
\text{public} = & & & & & & \\
\downarrow & & & & & & \\
\text{state}_a & \rightarrow & \text{state}_b & \rightarrow & \text{state}_c & \rightarrow & \cdots
\end{array}
$$

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an assertion about pairs of executions

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Hyperproperties

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Some security conditions are hyperproperties.

GNI (Generalized NonInterference)

Another example is GNI (short for Generalized NonInterference). ©

It assumes that an execution is a sequence of public and secret events. ©

It's a way of saying that the public events give you no information about the secret events. ©

For any two possible system executions ©

1 min 30 sec

Hyperproperties

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For any two possible system executions ©

GNI requires that you can get a possible system execution by combining ©

the public events of the first © with the secret events of the second. © ©

Again, it's an assertion about more than one execution. ©

1 min 30 sec

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$\uparrow$

$\text{public}_a \rightarrow \text{secret}_a \rightarrow \text{public}_b \rightarrow \text{public}_c \rightarrow \cdots$

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$\text{public}_a \rightarrow \text{secret}_a \rightarrow \text{public}_b \rightarrow \text{public}_c \rightarrow \cdots$

an assertion about multiple executions

For any two possible system executions ©
GNI requires that you can get a possible system execution by combining ©
the public events of the first © with the secret events of the second. © ©

Again, it's an assertion about more than one execution. ©

1 min 30 sec

Hyperproperties

Verification:

How do we verify © that a system satisfies a hyperproperty? © ©

1 min 37 sec

Hyperproperties

Verification:

$$S \models H$$

system — hyperproperty

How do we verify © that a system satisfies a hyperproperty? © ©

1 min 37 sec

Hyperproperties

Verification:

$$S \models H$$

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?

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1 min 37 sec

Verifying Properties

$S \models P$

Verifying ordinary properties © has been well-studied. ©

We want to make use of methods and tools developed to solve it. ©

So people have reduced verifying hyperproperties to verifying ordinary properties. Here's how. © Define two mappings.©

2 min 22 sec

Verifying Properties

$S \models P$ A well-studied problem.

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Verifying Hyperproperties by Verifying Properties

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 2 min 22 sec

Verifying Hyperproperties by Verifying Properties

Two mappings:

Define two mappings.©

The first maps a system S to another systems $\Omega(S)$. ©

The second maps a hyperproperty H to an ordinary property H-tilde. ©

These mapping are defined so that © system S satisfies hyperproperty H ©

if and only if the system $\Omega(S)$ satisfies the ordinary property H-tilde. ©

2 min 22 sec

Verifying Hyperproperties by Verifying Properties

Two mappings: $\Omega : S \rightarrow \Omega(S)$

system system

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Verifying Hyperproperties by Verifying Properties

Two mappings: $\Omega : S \rightarrow \Omega(S)$

system — system

$\widetilde{\ } : H \rightarrow \widetilde{H}$

hyperproperty — property

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Such that:

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Verifying Hyperproperties by Verifying Properties

Two mappings: $\Omega : S \rightarrow \Omega(S)$

system → system

$\widetilde{} : H \rightarrow \widetilde{H}$

hyperproperty → property

Such that: $S \models H$

Define two mappings. ©

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2 min 22 sec

Verifying Hyperproperties by Verifying Properties

Two mappings: $\Omega : S \rightarrow \Omega(S)$

S — system; $\Omega(S)$ — system

$\widetilde{\ } : H \rightarrow \widetilde{H}$

H — hyperproperty; $\widetilde{H}$ — property

Such that: $S \models H \quad \equiv \quad \Omega(S) \models \widetilde{H}$

Define two mappings.©

The first maps a system S to another systems $\Omega(S)$. ©

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These mapping are defined so that © system S satisfies hyperproperty H ©

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2 min 22 sec

Self-Composition

Verification has been done this way with a method called self-composition ©

where if hyperproperty H is an assertion about n executions ©

then $\Omega(S)$ is a big system that executes n copies of S in lock-step ©

and H tilde is H restated in terms of executions of the individual processes S in an execution of $\Omega(S)$.

2 min 50 sec

Self-Composition

If H is an assertion about n executions

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2 min 50 sec

Self-Composition

If H is an assertion about n executions

then $\Omega(S) \; = \; \underbrace{S \otimes S \ldots \otimes S}_{n \text{ copies}}$

executed in lock-step

Verification has been done this way with a method called self-composition ©

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2 min 50 sec

Self-Composition

If H is an assertion about n executions

then $\Omega(S) \; = \; S \otimes S \ldots \otimes S$

$\widetilde{H} \; = \; H$ stated in terms of executions of individual processes S

Verification has been done this way with a method called self-composition ©

where if hyperproperty H is an assertion about n executions ©

then $\Omega(S)$ is a big system that executes n copies of S in lock-step ©

and H tilde is H restated in terms of executions of the individual processes S in an execution of $\Omega(S)$.

2 min 50 sec

Self-Composition

Example: OD

For example, suppose the hyperproperty H is Observational Determinism. ©

Then $\Omega(S)$ consists of two copies of S run in lock step, and ©

H tilde asserts that, if those two copies of S start with equal public states, ©

then they will always have equal public states. ©

3 min 12 sec

Self-Composition

Example: OD

$$\Omega(S) \;=\; S \otimes S$$

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Example: OD

$$\Omega(S) \;=\; S \otimes S$$

$\widetilde{\mathrm{OD}}$ = If the copies of S start with equal public states then they always have equal public states.

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3 min 12 sec

Self-Composition – The Problem

There's a problem with this kind of Self-Composition. ©

It doesn't work for some security hyperproperties, including GNI. ©

GNI says that, for any two behaviors of S © there exists a
3rd behavior of S satisfying a certain condition. ©

With self-composition ©

3 min 51 sec

Self-Composition – The Problem

It doesn't work for GNI and . . .

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With self-composition ©

3 min 51 sec

Self-Composition – The Problem

GNI: For any two behaviors,

$$\text{public}_1 \rightarrow \text{secret}_1 \rightarrow \text{secret}_2 \rightarrow \text{public}_2 \rightarrow \cdots$$

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3 min 51 sec

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$\text{public}_1 \rightarrow \text{secret}_1 \rightarrow \text{secret}_2 \rightarrow \text{public}_2 \rightarrow \cdots$

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Self-Composition – The Problem

GNI: For any two behaviors, there exists a 3rd behavior.

Have to verify:

$\text{public}_1 \rightarrow \text{secret}_1 \rightarrow \text{secret}_2 \rightarrow \text{public}_2 \rightarrow \cdots$

$\text{public}_1 \rightarrow \text{secret}_a \rightarrow \text{public}_2 \rightarrow \cdots$

$\text{public}_a \rightarrow \text{secret}_a \rightarrow \text{public}_b \rightarrow \text{public}_c \rightarrow \cdots$

With self-composition © these two behaviors © are described by this big system $\Omega(S)$. ©

The 3rd behavior of S © is described by GNI, ©

So GNI-tilde must contain system S, which it can't because GNI-tilde is a property, and how can you put a system in a property?

3 min 51 sec

Self-Composition – The Problem

GNI: For any two behaviors, there exists a 3rd behavior.

Have to verify:

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Self-Composition – The Problem

GNI: For any two behaviors, there exists a 3rd behavior.

Have to verify: $S \otimes S$

$\Omega(S)$

public_1	$\rightarrow$	secret_1	$\rightarrow$	secret_2	$\rightarrow$	public_2	$\rightarrow$	$\cdots$
public_1	$\rightarrow$	secret_a	$\rightarrow$	public_2	$\rightarrow$	$\cdots$		
public_a	$\rightarrow$	secret_a	$\rightarrow$	public_b	$\rightarrow$	public_c	$\rightarrow$	$\cdots$

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Have to verify: $S \otimes S$

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$\text{public}_1 \rightarrow \text{secret}_a \rightarrow \text{public}_2 \rightarrow \cdots$

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Self-Composition – The Problem

GNI: For any two behaviors, there exists a 3rd behavior.

Have to verify: $S \otimes S \models \widetilde{GNI}$

described by GNI

public_1	$\rightarrow$	secret_1	$\rightarrow$	secret_2	$\rightarrow$	public_2	$\rightarrow$	$\cdots$
public_1	$\rightarrow$	secret_a	$\rightarrow$	public_2	$\rightarrow$	$\cdots$		
public_a	$\rightarrow$	secret_a	$\rightarrow$	public_b	$\rightarrow$	public_c	$\rightarrow$	$\cdots$

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Self-Composition – The Problem

GNI: For any two behaviors, there exists a 3rd behavior.

Have to verify: $S \otimes S \models \widetilde{GNI}$

described by GNI

must contain another copy of system S

public$_1$ $\rightarrow$ secret$_1$ $\rightarrow$ secret$_2$ $\rightarrow$ public$_2$ $\rightarrow \cdots$

public$_1$ $\rightarrow$ secret$_a$ $\rightarrow$ public$_2$ $\rightarrow \cdots$

public$_a$ $\rightarrow$ secret$_a$ $\rightarrow$ public$_b$ $\rightarrow$ public$_c$ $\rightarrow \cdots$

With self-composition © these two behaviors © are described by this big system $\Omega(S)$. ©

The 3rd behavior of S © is described by GNI, ©

So GNI-tilde must contain system S, which it can't because GNI-tilde is a property, and how can you put a system in a property?

3 min 51 sec

Self-Composition – Our Solution

Here is our solution ©

3 min 58 sec

Self-Composition – Our Solution

Works for GNI and . . .

Here is our solution © It works for some additional security properties, including GNI. ©

3 min 58 sec

TLA (temporal logic of actions)

We use the temporal logic TLA. ©

4 min 1 sec

TLA (temporal logic of actions)

Used by Microsoft, Amazon Web Services, Oracle, . . .

TLA has industrial-strength tools and is used by engineers who build large, distributed systems. ©

TLA describes systems, as well as properties, as formulas. ©

System S satisfies property P © means that the formula, S implies P is true. ©

The system obtained by running n copies of S in lock-step is defined as follows. ©

The definition begins with S (of x-sub-1), which is the formula obtained by substituting a new set of variables, x-sub-1, for the variables of S. ©

5 min 56 sec

TLA

Properties & systems are formulas.

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$S(x_1)$

S with new set x_1 of variables

The definition begins with S (of x-sub-1) which is the formula obtained by substituting a new set of variables, x-sub-1, for the variables of S. ©

Formula S (of x-sub-1) asserts that the values assumed by the variables of x-sub-1 during an execution satisfy the specification of system S. ©

And similarly for S of x-sub-2 through n, all different sets of variables. ©

In TLA conjunction is parallel composition, so this is a system composed of n copies of system S executing in parallel. ©

5 min 56 sec

TLA

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$S \otimes S \ldots \otimes S$ equals

$$S(x_1) \wedge S(x_2) \ldots \wedge S(x_n)$$

parallel composition of n copies of S

In TLA conjunction is parallel composition, so this is a system composed of n copies of system S executing in parallel. ©

and K asserts that the copies run in lock-step. I don't have time to explain how K is defined. ©

It's now easy to define define the property asserting that S satisfies GNI. ©

Here are the 2 copies of S that execute in lock-step.

5 min 56 sec

TLA

Properties & systems are formulas.

$$S \models P \quad \equiv \quad \models (S \Rightarrow P)$$

$S \otimes S \ldots \otimes S$ equals

$$S(x_1) \wedge S(x_2) \ldots \wedge S(x_n) \wedge K(x_1, \ldots, x_n)$$

copies run in lock-step

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$$S \models GNI$$

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$$S \models GNI \quad \equiv \quad \models (S(x_1) \wedge S(x_2) \wedge K(x_1, \ldots, x_n))$$

2 copies of S run in lock-step

Here are the 2 copies of S that execute in lock-step.
This composite system must satisfy–that is, this formula must imply– ©

that there exists another execution of S
represented by the values of variables x-sub 3 ©

with the right relation among the 3 executions—
that is, the values of the public variables of x-sub 3 equal those of x-sub 1
and the values of its secret variables equal those of x-sub-2. © ©

5 min 56 sec

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Properties & systems are formulas.

$$S \models P \quad \equiv \quad \models (S \Rightarrow P)$$

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$$S \models GNI \quad \equiv \quad \models (S(x_1) \wedge S(x_2) \wedge K(x_1, \ldots, x_n) \Rightarrow \exists\, x_3 : S(x_3))$$

exists a 3rd execution of S

Here are the 2 copies of S that execute in lock-step.
This composite system must satisfy–that is, this formula must imply– ©

that there exists another execution of S
represented by the values of variables x-sub 3 ©

with the right relation among the 3 executions—
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$$S \models GNI \quad \equiv \quad \models (S(x_1) \wedge S(x_2) \wedge K(x_1, \ldots, x_n) \Rightarrow \exists\, x_3 : S(x_3) \wedge L(x_1, x_2, x_3))$$

relation among the 3 executions

Here are the 2 copies of S that execute in lock-step.
This composite system must satisfy–that is, this formula must imply– ©

that there exists another execution of S
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Here are the 2 copies of S that execute in lock-step.
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and the values of its secret variables equal those of x-sub-2. © ©

5 min 56 sec

It’s Not So Easy

Unfortunately, expressing GNI is not this easy. ©

TLA, like most temporal logics, models a system execution as a sequence of **states**. ©

GNI and some other security hyperproperties were originally described in terms of executions as sequences of **events**. © ©

To translate from events to states, we model an event as a change of state.

6 min 22 sec

It's Not So Easy

TLA models executions as sequences of **states**.

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It's Not So Easy

TLA models executions as sequences of **states**.

GNI based on executions as sequences of **events**.

$\text{public}_1 \rightarrow \text{secret}_1 \rightarrow \text{secret}_2 \rightarrow \text{public}_2 \rightarrow \cdots$

Public **events** must reveal nothing about secret **events**.

Unfortunately, expressing GNI is not this easy. ©

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TLA models executions as sequences of **states**.

GNI based on executions as sequences of **events**.

Translate events to states by: $\text{event} = \text{state}_1 \rightarrow \text{state}_2$

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To translate from events to states, we model an event as a change of state.

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It's Not So Easy

For GNI, assume a state is (public state, secret state) .

To translate GNI, we assume a state is a (public-state, secret-state) pair. ©
Like this. ©

A public event © is one that changes the public state. ©

A secret event © is one that changes the secret state. ©

6 min 39 sec

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For GNI, assume a state is (public state, secret state) .

(4,“*foo*”)

public secret

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A public event $(4, \text{“}foo\text{”})$

public secret

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$$\cdots \rightarrow \text{public}_1 \rightarrow \text{secret}_1 \rightarrow \text{public}_2 \rightarrow \cdots$$

So this sequence of events © becomes this sequence of states. ©

This public event changes the public state. © This secret event changes the secret state. ©

So every event is either a public event or a secret event. ©
And the events are replaced by the state changes. ©

And similarly, this sequence of events ©
becomes this sequence of states. © ©

It's Not So Easy

For GNI, assume a state is (public state, secret state) .

$$\cdots \to \text{public}_1 \to \text{secret}_1 \to \text{public}_2 \to \cdots$$

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_2) \to \cdots$$

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7 min 4 sec

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$$\begin{array}{ccccccccc} & & \text{public}_1 & & \text{secret}_1 & & \text{public}_2 & & \\ \cdots \rightarrow & (p_1, s_1) & \rightarrow & (p_2, s_1) & \rightarrow & (p_2, s_2) & \rightarrow & (p_3, s_2) & \rightarrow \cdots \end{array}$$

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7 min 4 sec

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For GNI, assume a state is (public state, secret state) .

$$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_3, s_2) \rightarrow \cdots$$

$$\cdots \rightarrow \text{public}_1 \rightarrow \text{secret}_1 \rightarrow \text{secret}_2 \rightarrow \text{public}_2 \rightarrow \cdots$$

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And similarly, this sequence of events ©
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 7 min 4 sec

It’s Not So Easy

For GNI, assume a state is (public state, secret state) .

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_2) \to \cdots$$

$$\cdots \xrightarrow{} (p_1, s_1) \xrightarrow{\text{public}_1} (p_2, s_1) \xrightarrow{\text{secret}_1} (p_2, s_2) \xrightarrow{\text{secret}_2} (p_2, s_3) \xrightarrow{\text{public}_2} (p_3, s_3) \to \cdots$$

So this sequence of events © becomes this sequence of states. ©

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So every event is either a public event or a secret event. ©
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7 min 4 sec

It’s Not So Easy

GNI : If these system executions are run in lock-step

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_2) \to \cdots$$

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_2, s_3) \to (p_3, s_3) \to \cdots$$

The TLA version of GNI which I showed you before asserts that,
if these two system executions are run in lockstep ©
Then there exists a 3rd system execution ©
whose public states come from the 1st execution ©
and whose secret states come from the 2nd execution. ©
But there’s a problem here. ©
This state change changes the public state so it’s is a public event. ©

7 min 50 sec

It's Not So Easy

GNI : If these system executions are run in lock-step
then there exists a 3rd system execution...

$$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_3, s_2) \rightarrow \cdots$$

$$\cdots \rightarrow (\;,\;) \rightarrow (\;,\;) \rightarrow (\;,\;) \rightarrow (\;,\;) \rightarrow \cdots$$

$$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_2, s_3) \rightarrow (p_3, s_3) \rightarrow \cdots$$

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This state change changes the public state so it's is a public event. ©

7 min 50 sec

It's Not So Easy

GNI : If these system executions are run in lock-step
then there exists a 3rd system execution. . .

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_2) \to \cdots$$

$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$

$$\cdots \to (p_1, \;) \to (p_2, \;) \to (p_2, \;) \to (p_3, \;) \to \cdots$$

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_2, s_3) \to (p_3, s_3) \to \cdots$$

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7 min 50 sec

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This state change changes the public state so it's is a public event. ©

7 min 50 sec

It's Not So Easy

GNI : If these system executions are run in lock-step
then there exists a 3rd system execution. . .

$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_2) \to \cdots$

public

$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_3) \to \cdots$

$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_2, s_3) \to (p_3, s_3) \to \cdots$

This state change changes the public state so it's a public event. ©

This state change changes the secret state so it's is a secret event. ©

But this state change changes both the secret and public states,
which makes it both a public & secret event. ©

So this isn't a system execution, because GNI assumes that the system allows state changes that are either public or secret events, but not both. ©

It's Not So Easy

GNI : If these system executions are run in lock-step
then there exists a 3rd system execution. . .

$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_3, s_2) \rightarrow \cdots$

public

$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_3, s_3) \rightarrow \cdots$

secret

$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_2, s_3) \rightarrow (p_3, s_3) \rightarrow \cdots$

This state change changes the public state so it's a public event. ©

This state change changes the secret state so it's is a secret event. ©

But this state change changes both the secret and public states,
which makes it both a public & secret event. ©

So this isn't a system execution, because GNI assumes that the system allows
state changes that are either public or secret events, but not both. ©

7 min 50 sec

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public   public

$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_3) \to \cdots$

secret   secret

$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_2, s_3) \to (p_3, s_3) \to \cdots$

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public public

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secret secret

$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_2, s_3) \rightarrow (p_3, s_3) \rightarrow \cdots$

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It’s Not So Easy

GNI : If any two system executions are run in lock-step then . . .

This problem is inherent in our TLA definition of GNI. ©

The definition is wrong. ©

It's Not So Easy

~~GNI : If any two system executions are run in lock-step then . . .~~

This definition is wrong.

This problem is inherent in our TLA definition of GNI. ©

The definition is wrong. ©

7 min 58 sec

Getting It Right

Instead of being in lock-step,

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_3, s_2) \to \cdots$$

$$\cdots \to (p_1, s_1) \to (p_2, s_1) \to (p_2, s_2) \to (p_2, s_3) \to (p_3, s_3) \to \cdots$$

Instead of having to execute the two copies of the system in lock-step ©

A correct definition of GNI should allow them to be executed like this. ©

GNI assumes these two executions appear the same to public users ©

who just see this. ©

Most formalisms consider these to be different executions because of this extra state. ©

but that means users can tell when secret events occur between public events. ©

TLA considers these two executions to be the same because that extra step leaves the state seen by the user unchanged. ©

 8 min 36 sec

Getting It Right

Instead of being in lock-step, the executions should be:

$$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_3, s_2) \rightarrow \cdots$$

$$\cdots \rightarrow (p_1, s_1) \rightarrow (p_2, s_1) \rightarrow (p_2, s_2) \rightarrow (p_2, s_3) \rightarrow (p_3, s_3) \rightarrow \cdots$$

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$$\cdots \to (p_1,\ \ ) \to (p_2,\ \ ) \to (p_2,\ \ ) \to \boxed{(p_2,\ \ )} \to (p_3,\ \ ) \to \cdots$$

Most formalisms consider these to be different executions

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Getting It Right

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Most formalisms consider these to be different executions, implying users can tell when secret events occur between public ones.

Instead of having to execute the two copies of the system in lock-step ©

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GNI assumes these two executions appear the same to public users ©

who just see this. ©

Most formalisms consider these to be different executions because of this extra state. ©

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TLA considers these two executions to be the same because that extra step leaves the state seen by the user unchanged. ©

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Getting It Right

Instead of being in lock-step, the executions should be:

GNI assumes they are the same to public users.

$\cdots \rightarrow (p_1, \ \ ) \rightarrow (p_2, \ \ ) \rightarrow (p_2, \ \ ) \rightarrow (p_3, \ \ ) \rightarrow \cdots$

$\cdots \rightarrow (p_1, \ \ ) \rightarrow (p_2, \ \ ) \rightarrow \boxed{(p_2, \ \ ) \rightarrow (p_2, \ \ )} \rightarrow (p_3, \ \ ) \rightarrow \cdots$

TLA considers them the same because the extra step leaves the visible state unchanged.

Instead of having to execute the two copies of the system in lock-step ©

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TLA considers these two executions to be the same because that extra step leaves the state seen by the user unchanged. ©

TLA

TLA seems strange because steps that leave the state unchanged can't be required or forbidden by a formula.

TLA at first seems strange to most people because steps that leave the state unchanged can't be required or forbidden by a TLA formula. ©

But that's one reason TLA is simple. ©

This restriction helps ensure that a spec can assert only what it should. ©

For example, a specification of an hour minute clock should not assert that the clock © does not display the temperature © or doesn't display seconds. ©

A **TLA** spec **can't** say that. ©

That's why implementation is simply implication. ©

9 min 11 sec

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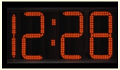
A spec of an hour-minute clock



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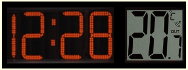

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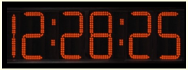

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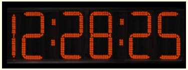

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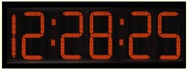
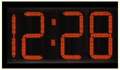


$\Rightarrow$



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A main contribution of the paper:

A main contribution of the paper is that ©

This feature of TLA is also important for expressing hyperproperties. ©

9 min 21 sec

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TLA

Steps that leave the state unchanged can't be required or forbidden.

This feature © provides flexibility in aligning executions. ©

It enables simple specifications of a class of hyperproperties that includes GNI. ©

You'll have to read the paper to find out how it's done. It's not obvious. ©

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In the Paper

What's in the paper? ©

I've been doing a lot of hand-waving. The paper contains the details. ©

They're explained with two toy systems that satisfy GNI. ©

There are TLA specifications of these other security hyperproperties. ©

There's a characterization of when a hyperproperty is preserved under refinement. ©

The paper contains toy examples, but TLA is not a toy.

10 min 33 sec

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Relation to machine-checked TLA proof of OD for a real system

The paper contains toy examples, but TLA is not a toy.

Others have written a machine-checked TLA proof of observational determinism for a real-time message passing system that was later commercialized.

The paper explains the relation of that work to ours. ©

10 min 33 sec

On the Web

On the Web, you can find ©

Model-checked TLA specifications of the examples in the paper. ©

And all about TLA so you can try it yourself.

Thank you.

On the Web

TLA specs of the examples in the paper

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10 min 45 sec

On the Web

TLA specs of the examples in the paper

TLA documentation & tools:

`https://lamport.azurewebsites.net/tla/tla.html`

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