

Example from yesterday

Pulsed request signal `req`

Requirement:

Before can make a second request, the first must be acknowledged

What if we want to allow the `ack` to come not together with the next `req` but with the `req` that it is acknowledging?? Write a new property for this.

A: `assert always (req -> (ack || next (ack before req)))`

Sequential Extended Regular Expressions (SEREs)

(based on source : Dana Fisman and Cindy Eisner,
with thanks)

SEREs

Alternative to the temporal operators (always, next, until, before)

Related to good old regular expressions

A SERE is a property but a property is not necessarily a SERE

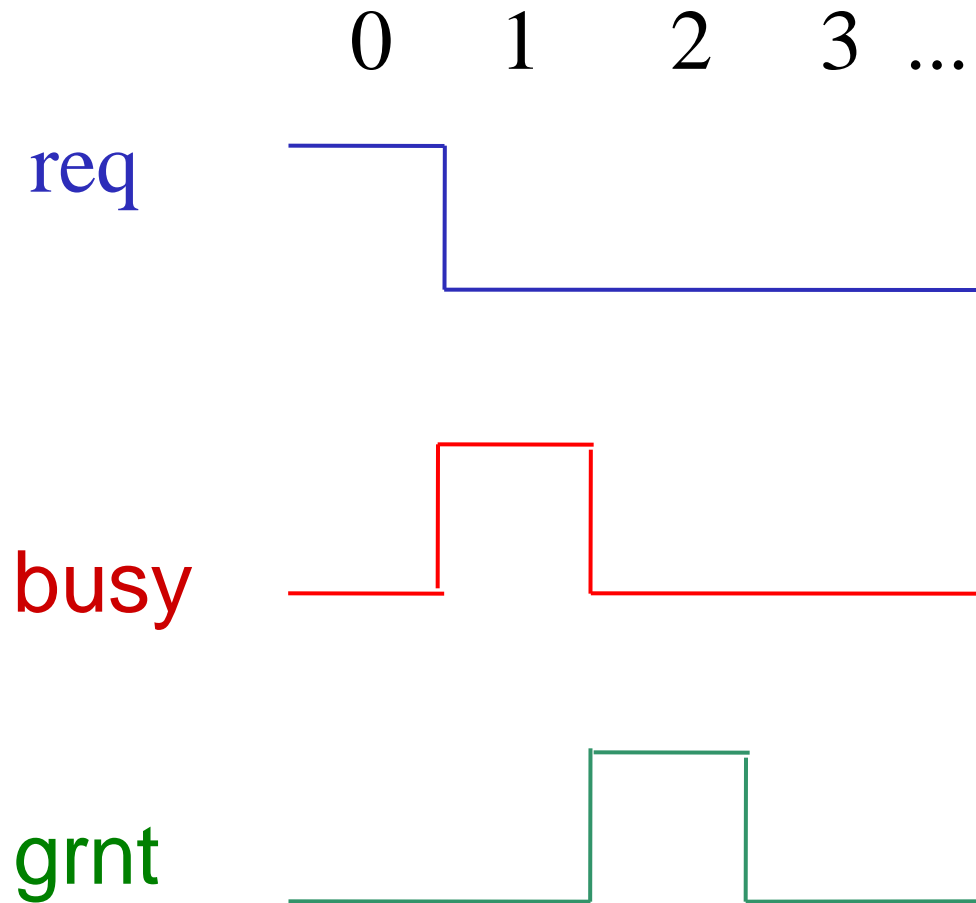
SERE examples

```
assert {req; busy; grnt}
```

req is high on the first cycle, busy on the second, and grnt on the third.

SERE examples

assert {req; busy; grnt}

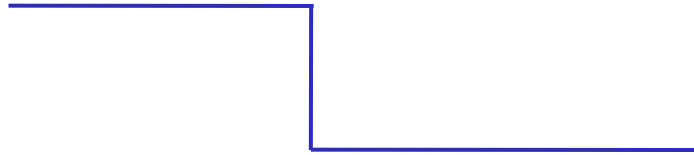


SERE examples

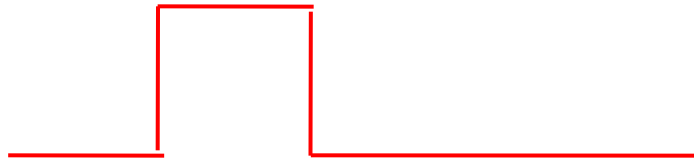
assert {req; busy; grnt}

0 1 2 3 ...

req



busy



grnt



this too

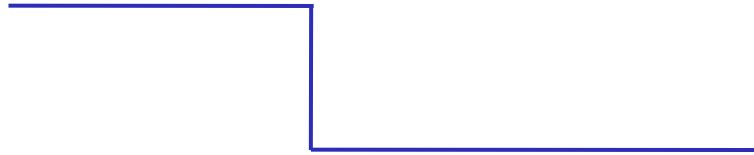


SERE examples

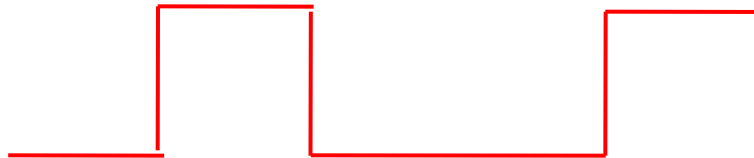
assert {req; busy; grnt}

0 1 2 3 ...

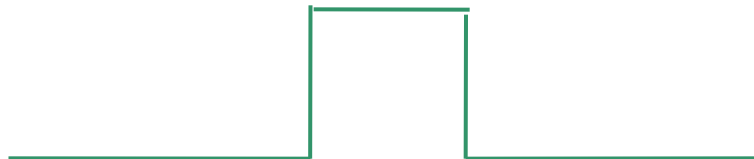
req



busy



grnt



and this

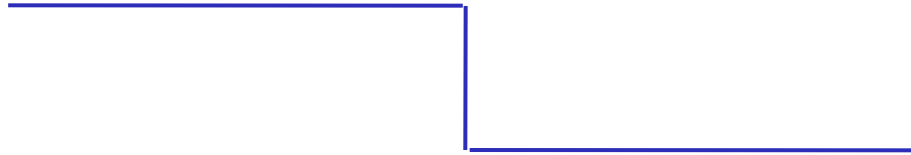


SERE examples

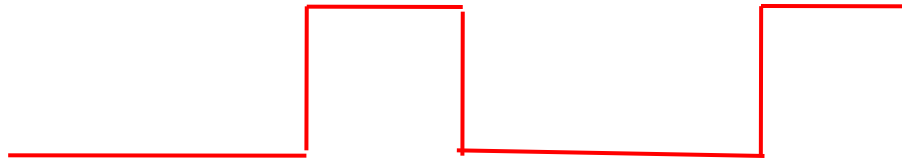
assert {req; busy; grnt}

0 1 2 3 ...

req



busy



grnt



but not this

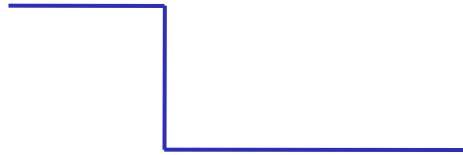
Why?

SERE examples

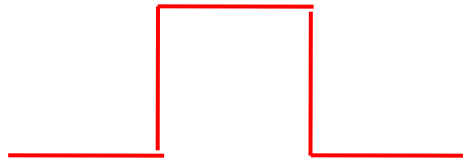
Specify only traces that start like this?

0 1 2 3 ...

req



busy



grnt

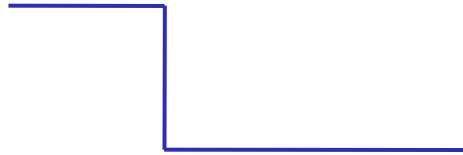


SERE examples

Specify only traces that start like this?

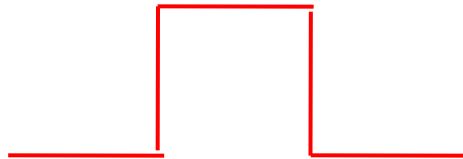
0 1 2 3 ...

req



assert {req and not busy and not grnt;
not req and busy and not grnt;
not req and not busy and grnt}

busy

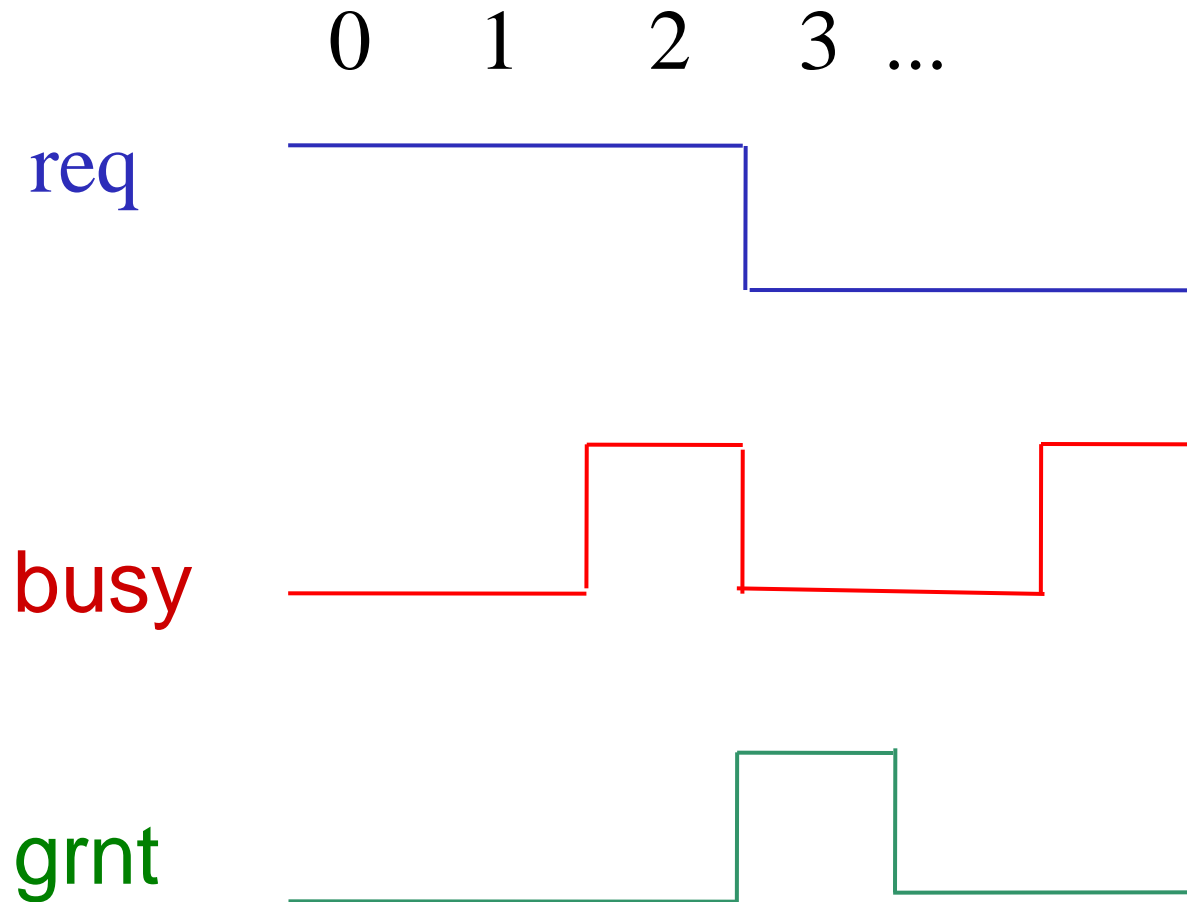


grnt

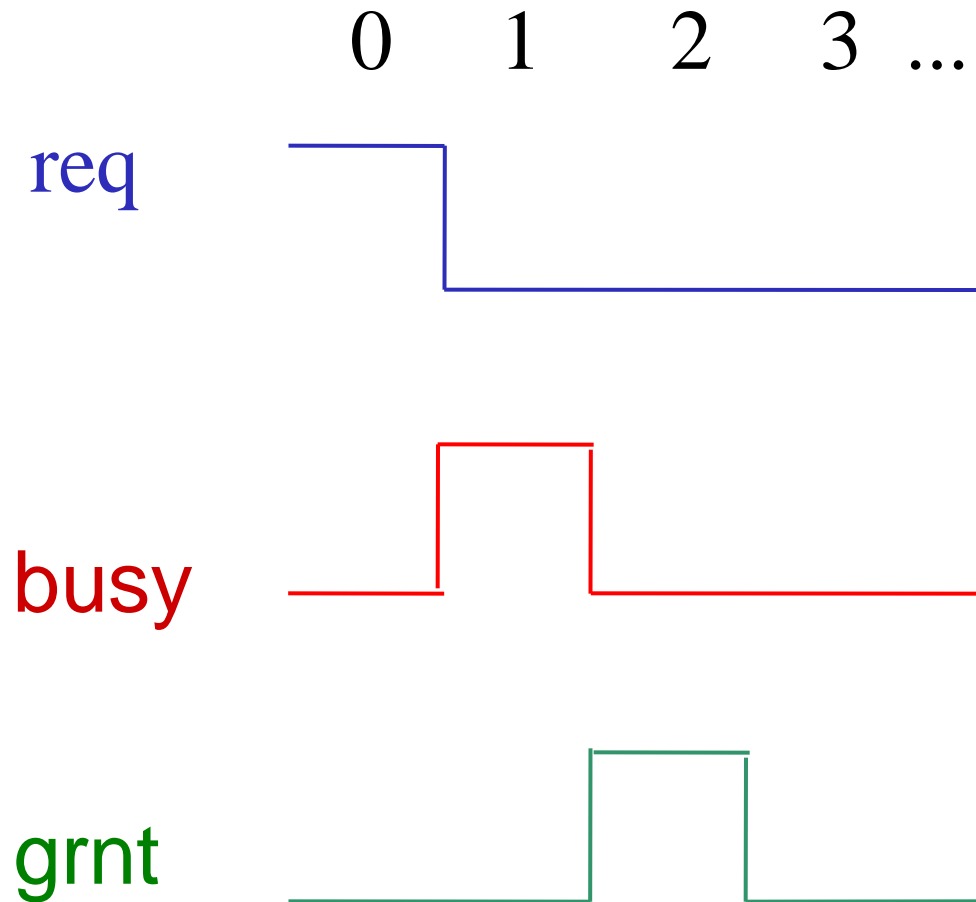


assert {[*]; req; busy; grnt}

[*] means skip
zero or more
cycles



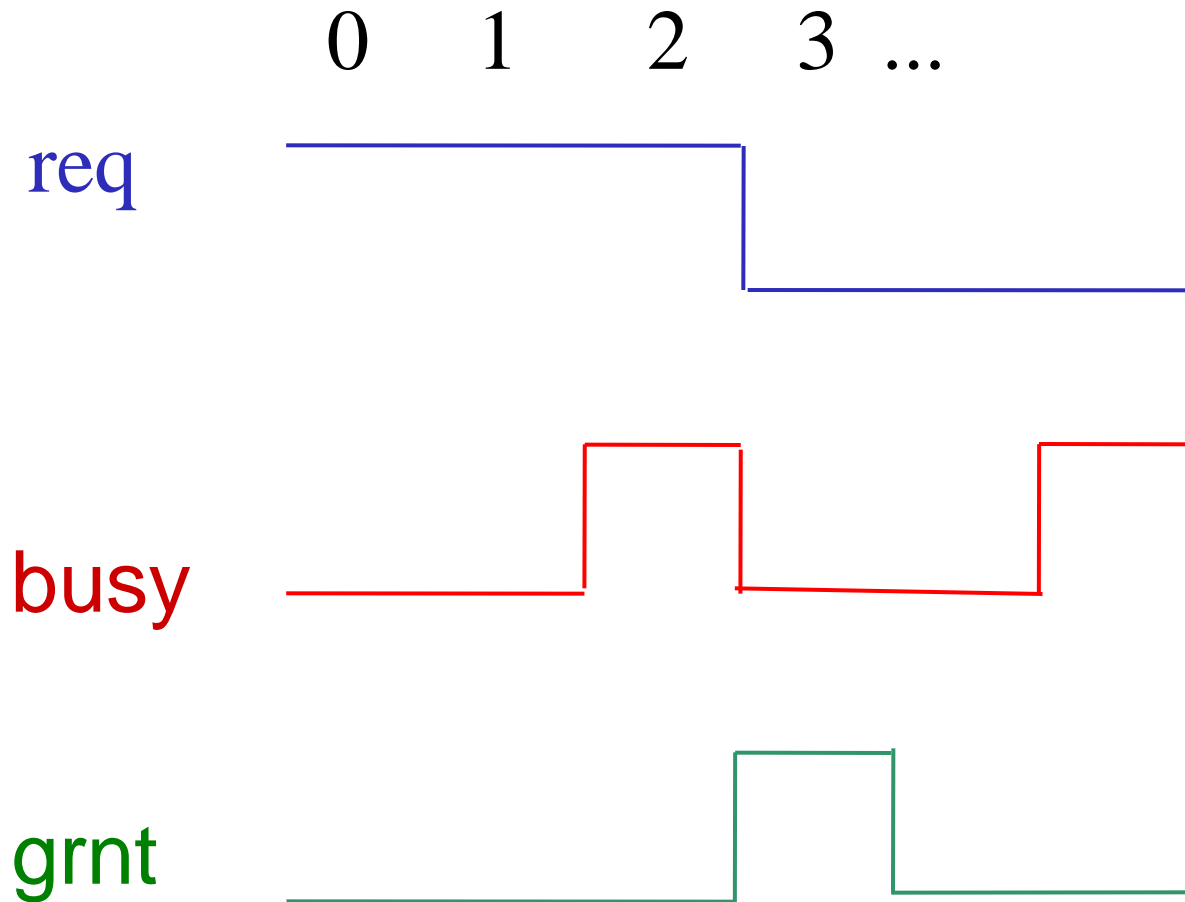
assert {[*]; req; busy; grnt}



so our original trace
is still in the set
described



`assert {true; req; busy; grnt}`



says
req;busy;grnt
should start
after one cycle

constrains only
cycles 1,2,3



{true[*4]; req; busy; grnt} 4 repetitions

{true[+]; req; busy; grnt} true[+] = [+]

one or more trues

true[*] = [*]

{[*]; req; busy[*3 to 5]; grnt}

at least 3 and at most 5 busys

{[*]; req; {b1;b2}[*]; grnt}

{[*]; req; {b1;b2;b3}[*7]; grnt}

subsequences can also be repeated

Yet more SERE repetition operators

```
{[*]; req; busy[=3]; grnt}
```

3 busys, not necessarily in consecutive cycles, between
req and grnt

(and with possible "padding" before and after
occurrences of busy)

Applies only to Boolean expressions

(example trace later)

Yet more SERE repetition operators

```
{[*]; req; busy[->3]; grnt}
```

3 busys, not necessarily in consecutive cycles, between
req and grnt

(and with possible "padding" before, but NOT after last
occurrence of busy)

Applies only to Boolean expressions

Called the "goto repetition operator"

[->1] can be written [->]

&&

Simultaneous subsequences

Same length, start and end together

{start; a[*]; end} && {!abort[*]}

"length matching and"

&

Both sequences should be matched, starting at the same clock cycle

But they don't need to be the same length

`{p1_done[->] & p2_done[->] & p3_done[->]}`

Describes an interval in which p1, p2 and p3 all get done, but not necessarily simultaneously

|

One of the subsequences should be matched (or)
Don't need to be the same length

```
{request;  
{rd; not c_r; not dne[*]} | {wr; not c_w; not dne[*]};  
dne}
```

Fancier properties at last!

SEREs are themselves properties

Properties are also built from subproperties

$\{\text{SERE1}\} \Rightarrow \{\text{SERE2}\}$ is a property

If a trace matches SERE1, then its continuation should match SERE2

Fancier properties at last!

SEREs are themselves properties

Properties are also built from subproperties

$\{\text{SERE1}\} \models \{\text{SERE2}\}$ is a property

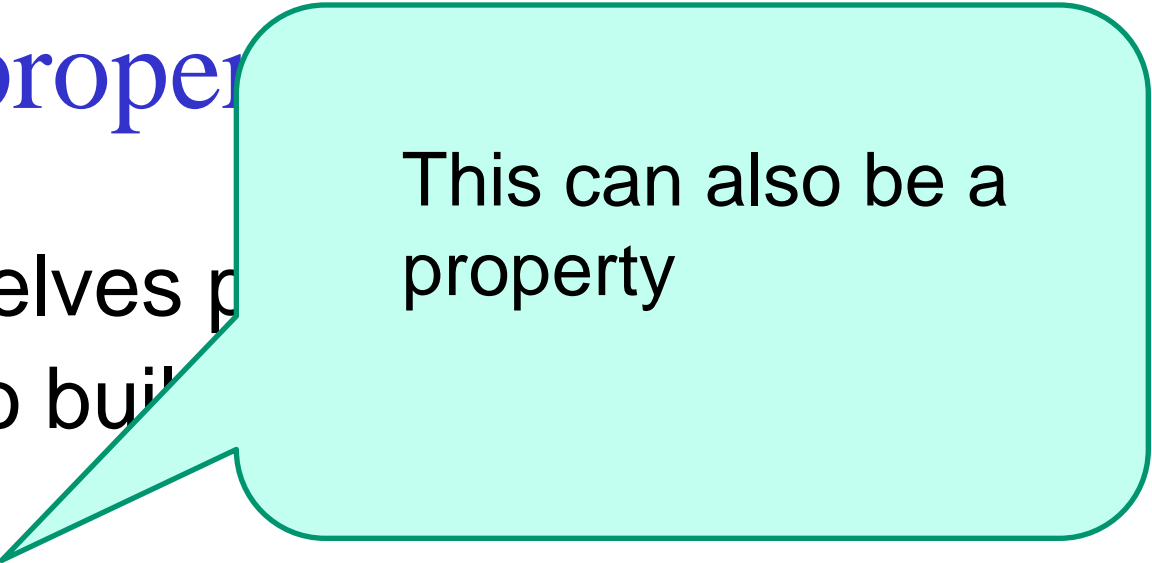
If a trace matches
continuation should

Non-overlapping suffix
implication

Fancier properties

SEREs are themselves properties

Properties are also built from SEREs

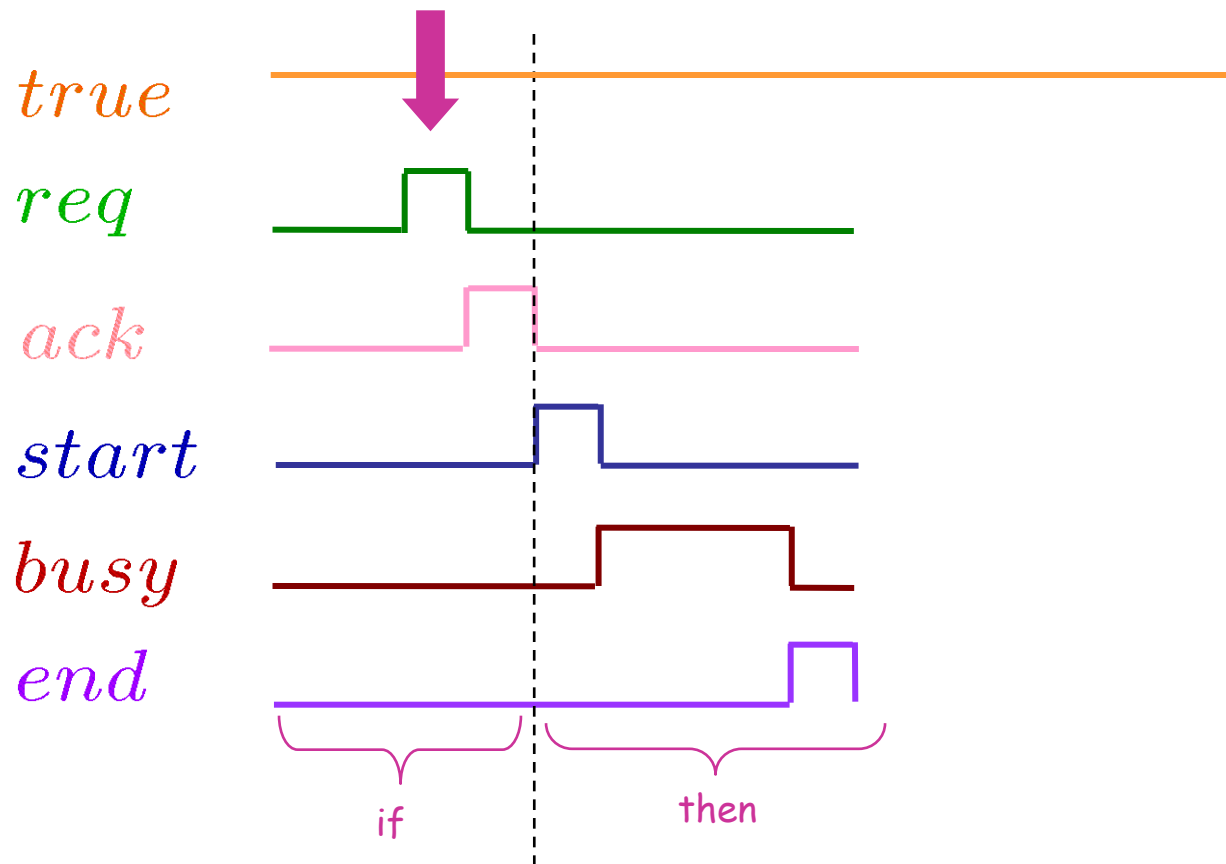


This can also be a property

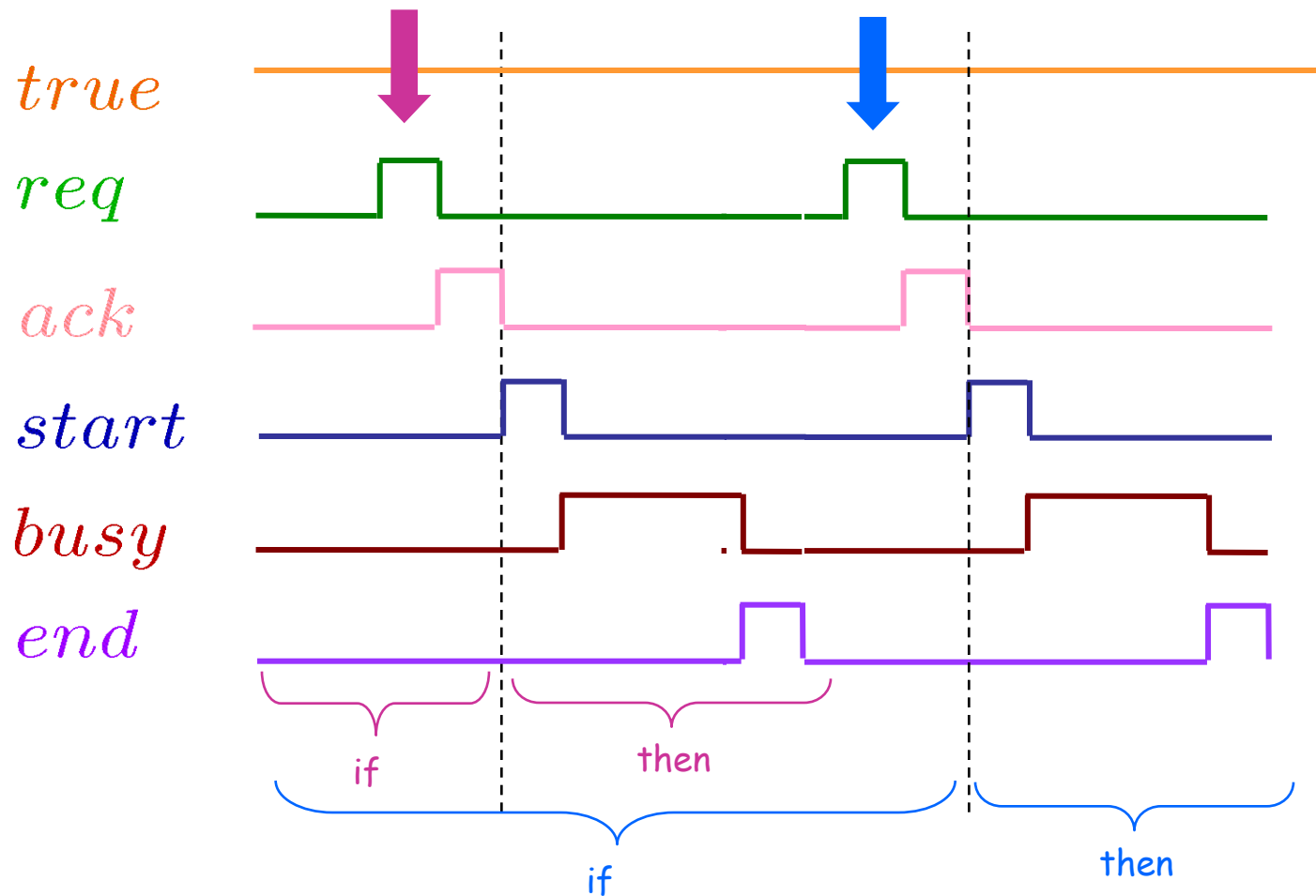
$\{\text{SERE1}\} \Rightarrow \{\text{SERE2}\}$ is a property

If a trace matches SERE1, then its continuation should match SERE2

$\{\text{true}[*]; \text{req}; \text{ack}\} \Rightarrow \{\text{start}; \text{busy}[*]; \text{end}\}$

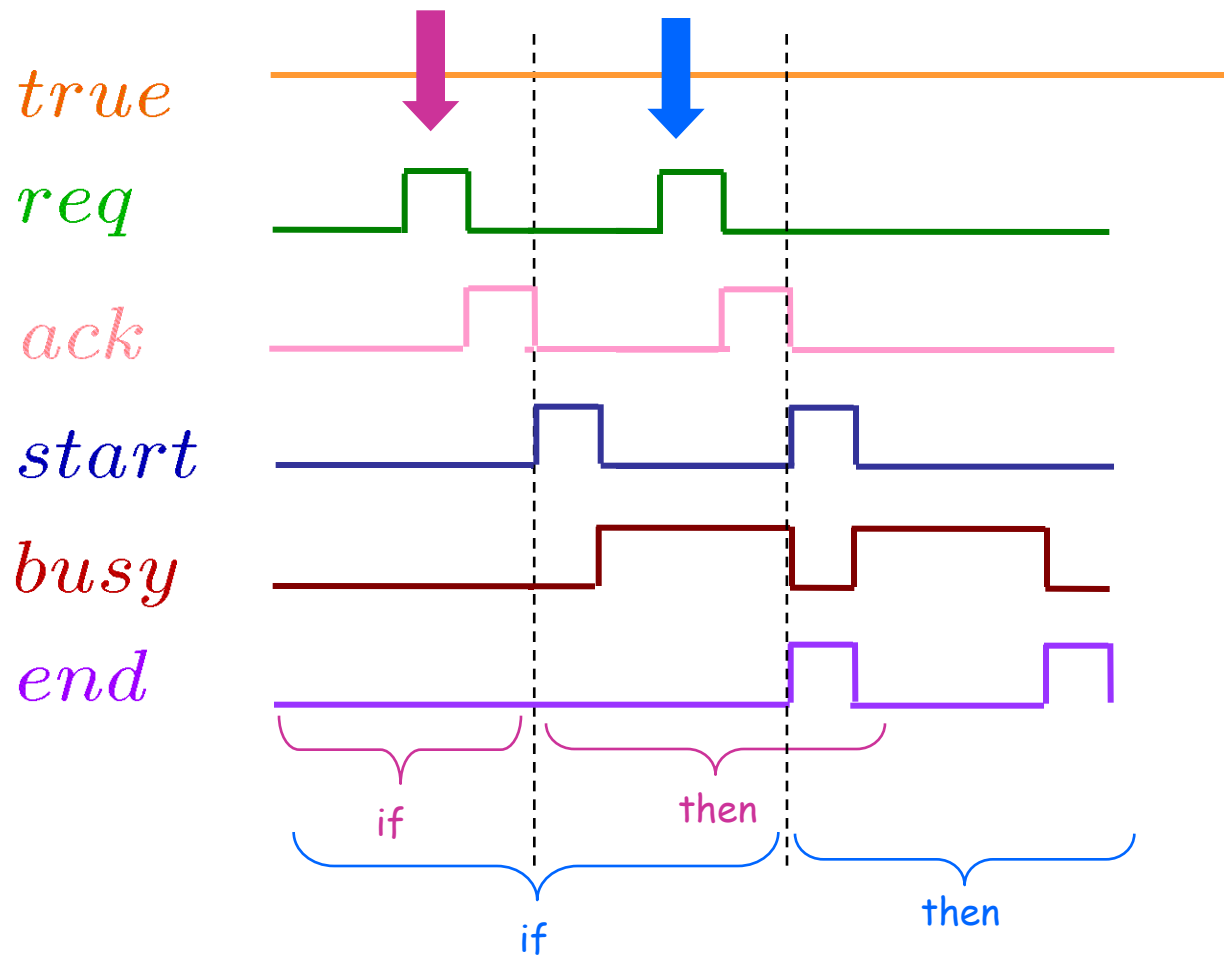


Not just the first req; ack
 $\{true[*]; req; ack\} \Rightarrow \{start; busy[*]; end\}$

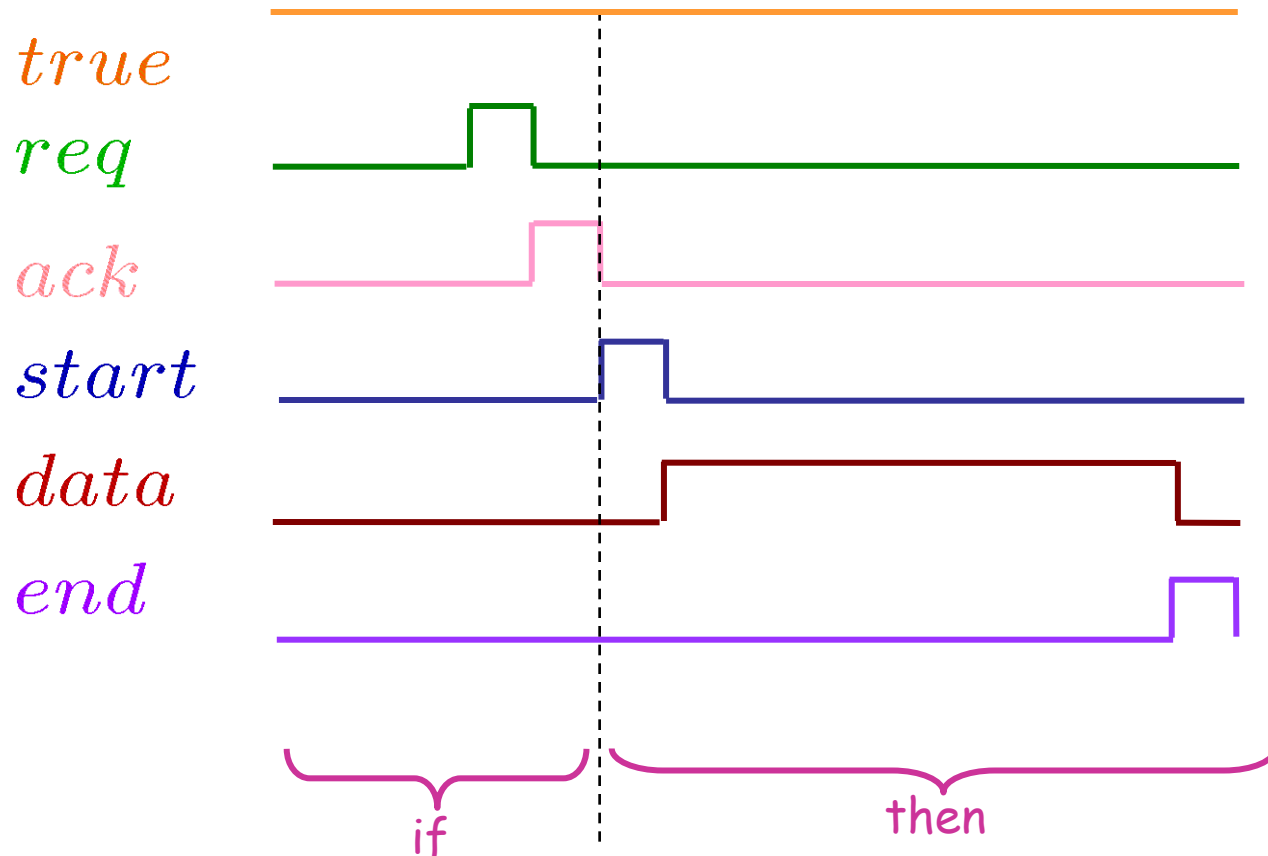


Overlap also possible!

$\{\text{true}[*]; \text{req}; \text{ack}\} \Rightarrow \{\text{start}; \text{busy}[*]; \text{end}\}$

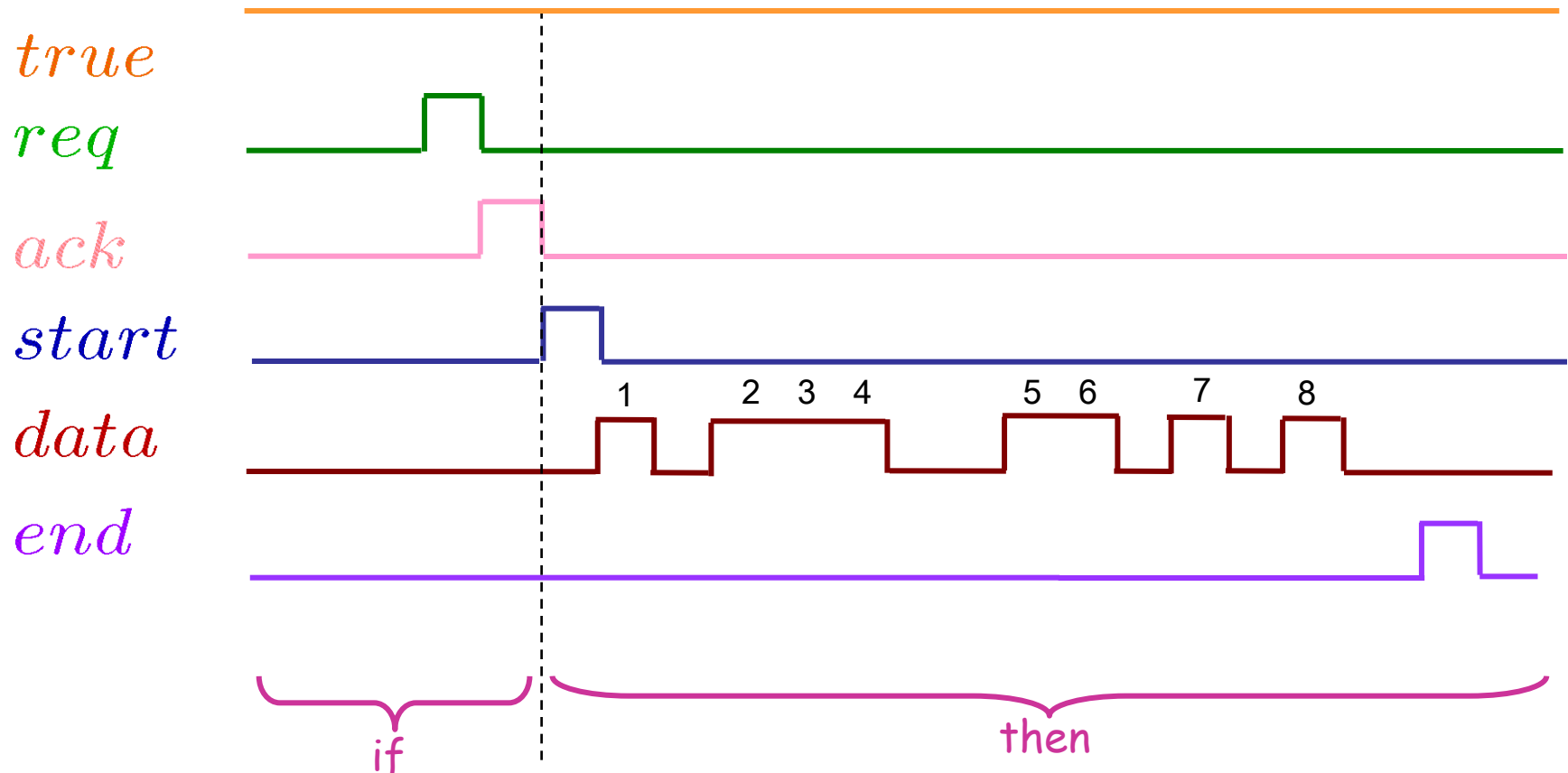


$\{\text{true}[*]; \text{req}; \text{ack}\} \models \{\text{start}; \text{data}[*]; \text{end}\}$



Can check for data in non-consecutive cycles

$\{true[*]; req; ack\} \Rightarrow \{start; data[=8]; end\}$



A form of implication

$\{\text{SERE1}\} \Rightarrow \{\text{SERE2}\}$

If a trace matches SERE1, then its continuation should match SERE2

A form of implication

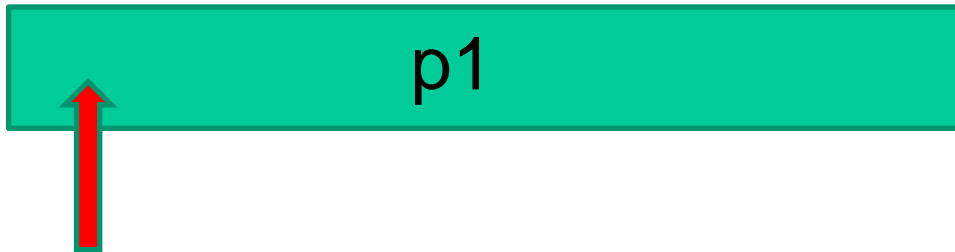
v. similar to logical implication

(with same "false implies everything" trap)

Difference is timing relationship between if and then parts

logical implication

$p1 \rightarrow p2$

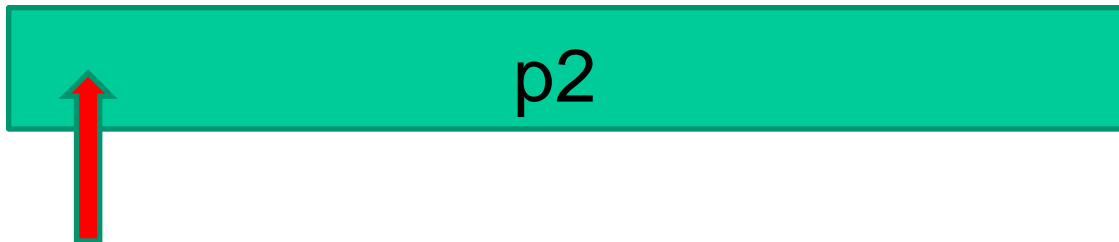


logical implication

$p1 \rightarrow p2$



\rightarrow



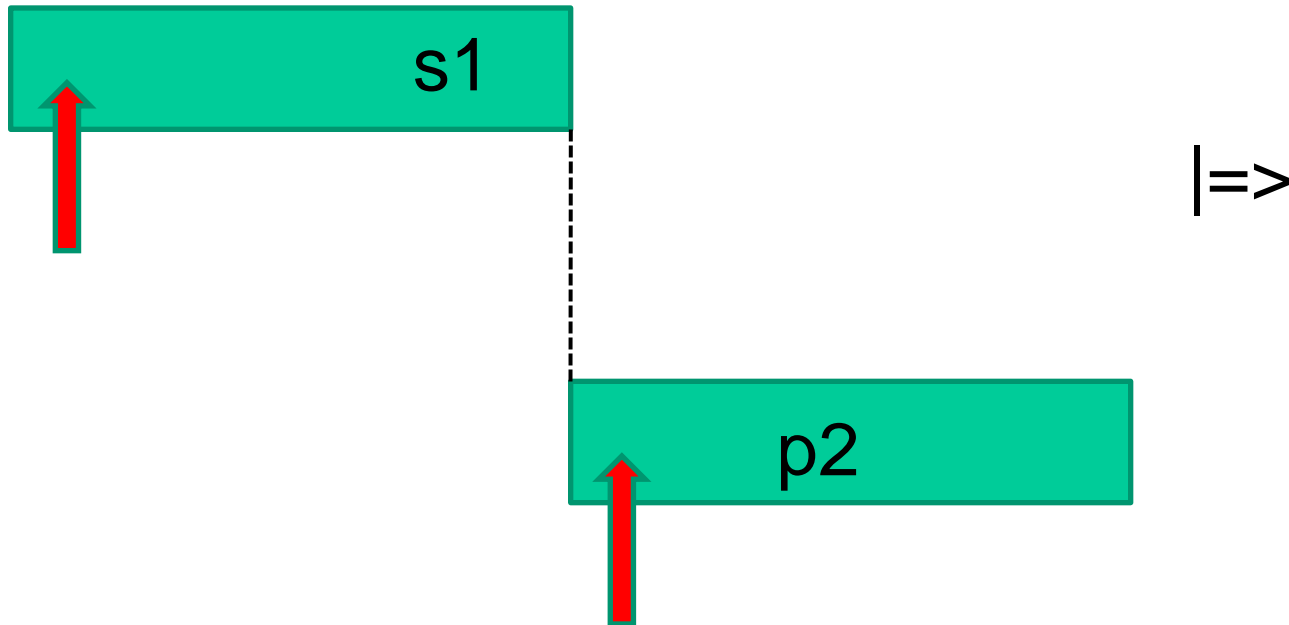
suffix implication

$s1 \models p2$



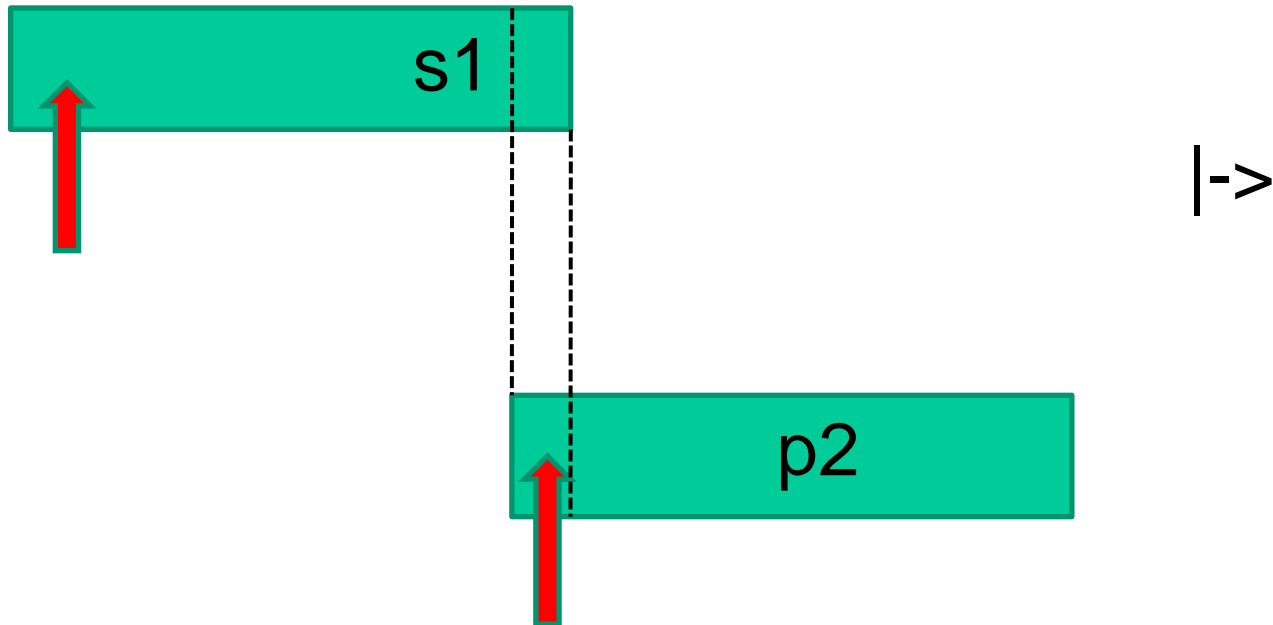
suffix implication

$s1 \models p2$



overlapping suffix implication

$s1 \dashv\rightarrow p2$



Another form of implication

$\{\text{SERE1}\} \rightarrow \{\text{SERE2}\}$

If a trace matches SERE1, then SERE2 should be matched, starting from the last element of the trace matching SERE1

So there is one cycle of overlap in the middle

Example

$\{[*]; \text{start}; \text{busy}[*]; \text{end}\} \rightarrow \{\text{success}; \text{done}\}$

If signal start is asserted, signal end is asserted at the next cycle or later, and in the meantime signal busy holds, then success is asserted at the same time as end is, and in the next cycle done is asserted

Example

$\{[*]; \{\{\text{start}; c[*]; \text{end}\} \& \& \{\text{not abort}[*]\}\}\} \mapsto \{\text{success}\}$

If there is no abort during $\{\text{start}; c[*]; \text{end}\}$,
success will be asserted with end

Question

Can you express one of the suffix implications in terms of the other?

Don't forget always!

$\{[*];s\} \rightarrow p$

(SERE style)

equivalent to

always $\{s\} \rightarrow p$

(LTL style)

(and sim. for \Rightarrow)

PSL has a small core and the rest is syntactic sugar, for example

$b[=i] = \{\text{not } b[*]; b\}[*i] ; \text{not } b[*]$

Q: define $b[->k]$ in similar style

See formal semantics in LRM

PSL

Regular expressions (plus some operators)

+

Linear temporal logic (LTL)

+

Lots of syntactic sugar

+ (optional)

Computation tree logic (CTL)

Example revisited

A sequence beginning with the assertion of signal `strt`, and containing **two** not necessarily consecutive assertions of signal `get`, during which signal `kill` is not asserted, must be followed by a sequence containing **two** assertions of signal `put` before signal `end` can be asserted

$$\text{AG} \sim (\text{strt} \ \& \ \text{EX} \ \text{E}[\sim \text{get} \ \& \ \sim \text{kill} \ \text{U} \ \text{get} \ \& \ \sim \text{kill} \ \& \ \text{EX} \ \text{E}[\sim \text{get} \ \& \ \sim \text{kill} \ \text{U} \ \text{get} \ \& \ \sim \text{kill} \ \& \ \text{E}[\sim \text{put} \ \text{U} \ \text{end}] \ \text{or} \ \text{E}[\sim \text{put} \ \& \ \sim \text{end} \ \text{U} \ (\text{put} \ \& \ \sim \text{end} \ \& \ \text{EX} \ \text{E}[\sim \text{put} \ \text{U} \ \text{end}])]]])$$

In PSL (with 8 for 2)

A sequence beginning with the assertion of signal strt, and containing **eight** not necessarily consecutive assertions of signal get, during which signal kill is not asserted, must be followed by a sequence containing **eight** assertions of signal put before signal end can be asserted

`always({strt; {get[=8]}&&{kill[=0]}}`

`|=> {{put[=8]}&&{end[=0]}})`

PSL

Seems to be reasonably simple, elegant and concise!

Jasper's Göteborg based team have helped to define and simplify the formal semantics.

See the LRM (or IEEE standard) and also the paper in FMCAD 2004