Naturalized Communication and Testing

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ASYNC 2015, 3-6 May

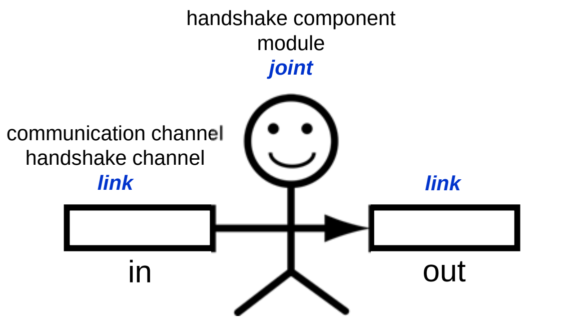
Outline

PART 1: naturalized communication
- exposes the fundamental pipeline actions underlying all handshakes
- to obtain a standard protocol interface for translation-free communication
- to simplify the exchange of designs + tools

PART 2: naturalized testing
- emphasizes the role of actions
- by using dedicated action control: MrGO
- to safely start, stop, and freeze actions individually
- for single-step, multi-step, and at-speed test + debug

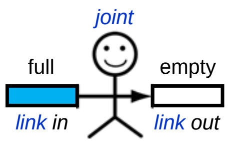
PART 1
naturalized communication

Dataflow pipeline: building blocks

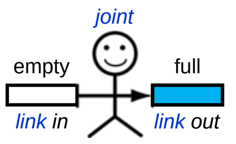


Dataflow pipeline: action

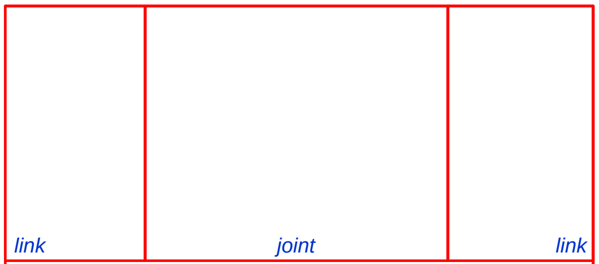
WHEN to act:
in is full
and
out is empty



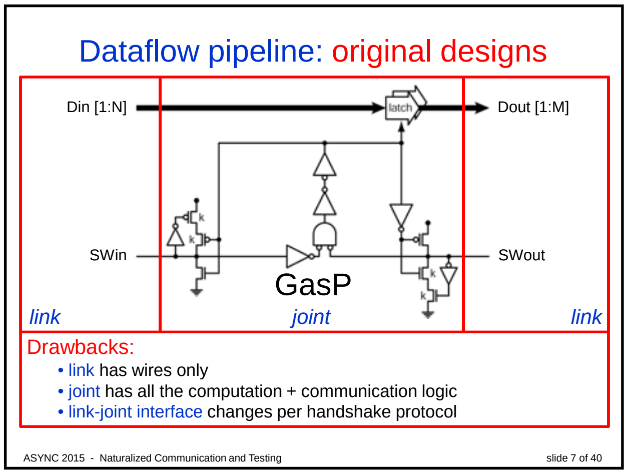
WHAT to do:
- copy data
- drain *in*
- fill *out*



Dataflow pipeline: original designs



Drawbacks:
- link has wires only
- joint has all the computation + communication logic
- link-joint interface changes per handshake protocol



Dataflow pipeline: original designs

Drawbacks:
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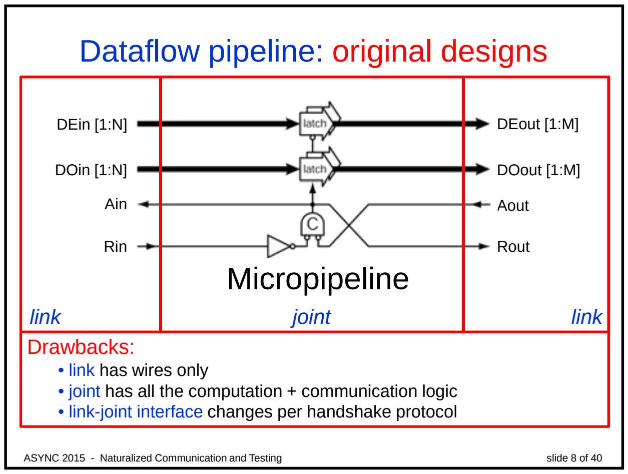

Dataflow pipeline: original designs

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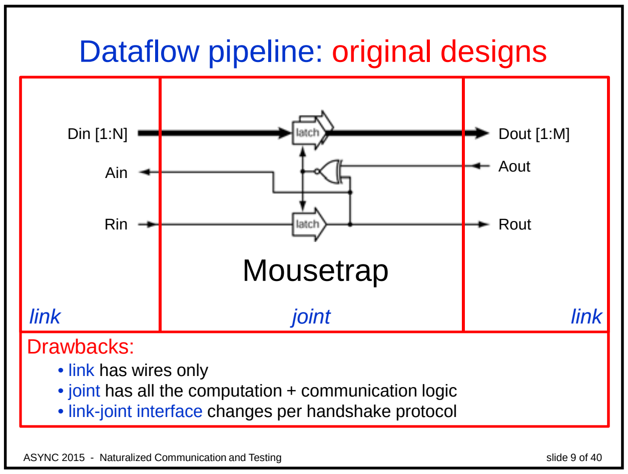

Dataflow pipeline: original designs

Drawbacks:
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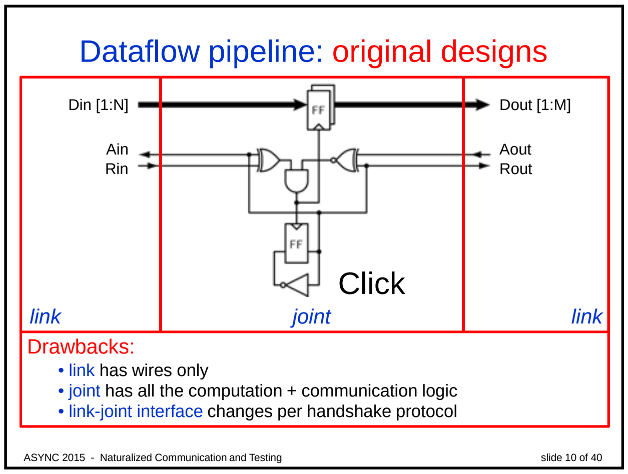

Dataflow pipeline: original designs

Drawbacks:
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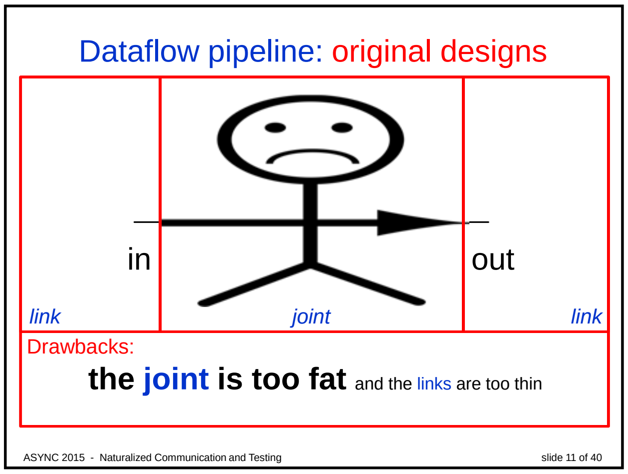

Dataflow pipeline: original designs

Drawbacks:

the joint is too fat and the links are too thin

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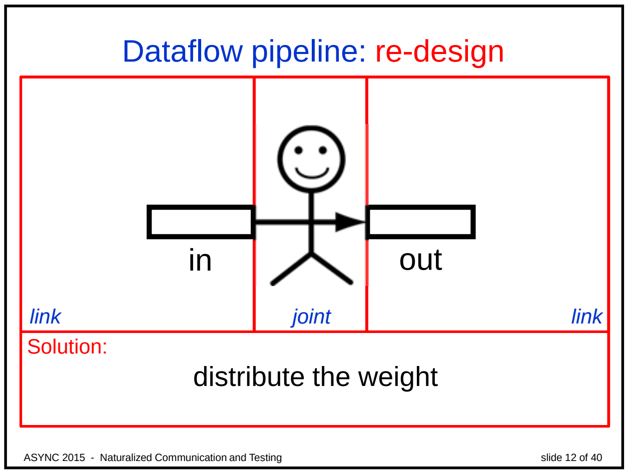

Dataflow pipeline: re-design

Solution:

distribute the weight

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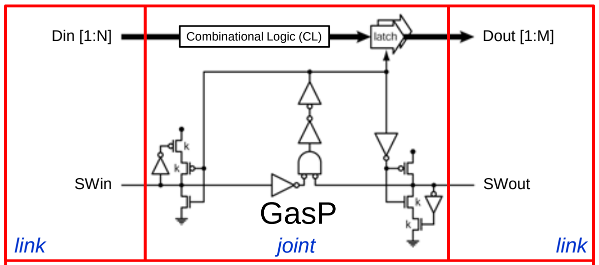
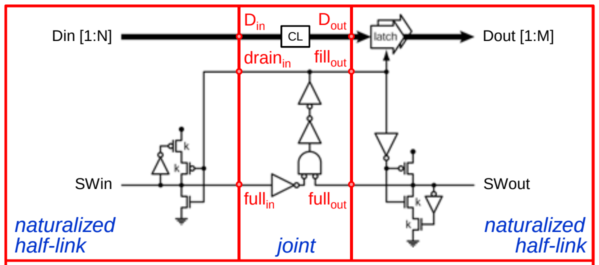
Dataflow pipeline: re-design from



Solution:
- move the link-joint interface
- by moving the communication logic from the joint to the links
- such that link-joint interface signals match those in the pipeline action

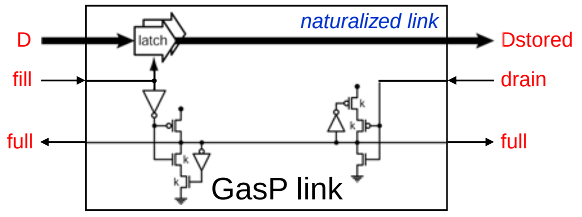
Dataflow pipeline: re-design to



Solution:
- move the link-joint interface
- by moving the communication logic from the joint to the links
- such that link-joint interface signals match those in the pipeline action

Naturalized communication: take-away

- by exposing the fundamental pipeline signals: full-empty, drain, fill, D
- we can standardize the link-joint interface
- and simplify + share designs and tools



Naturalized communication: take-away

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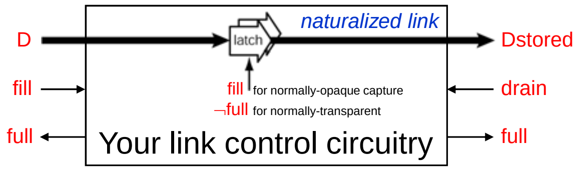
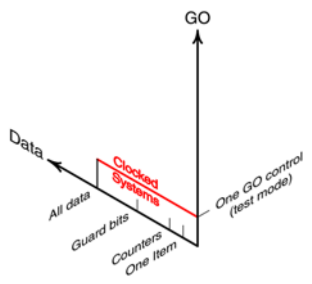
- and simplify + share designs and tools


naturalized link
D
latch
Dstored
fill
fill for normally-opaque capture
¬full for normally-transparent
drain
full
full
Your link control circuitry

PART 2
naturalized testing
(silicon)

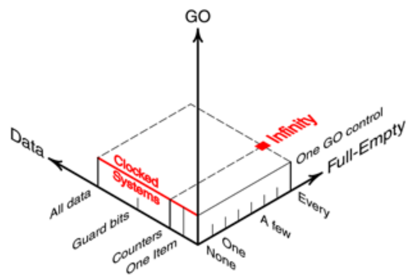
Naturalized testing: where we came from

- synchronous systems
- start and stop the global clock action : One GO control
- use scan test to control + observe global state : Data
- to detect stuck-at faults



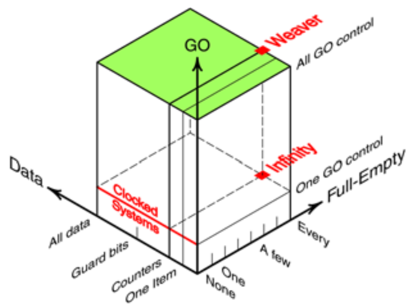
Naturalized testing: where we are

- self-timed systems
- start and stop all local actions together : One GO control
- use scan test to control + observe local state : Data + Full-Empty
- to detect stuck-at faults



Naturalized testing: and where we go

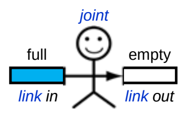
- stuck-at fault detection & beyond: at-speed test / debug / characterization
- start and stop each local action individually : All GO control



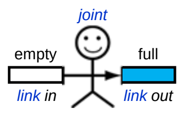
dedicated action control

Dataflow pipeline: action reminder

WHEN to act:
in is full
and
out is empty

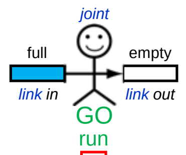


WHAT to do:
- copy data
- drain *in*
- fill *out*

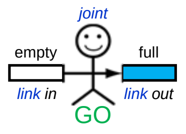


Dataflow pipeline: action with GO control

WHEN to act:
in is full
and
out is empty
and
GO



WHAT to do:
- copy data
- drain *in*
- fill *out*



Dataflow pipeline: action with GO control

WHEN to act:
in is full
and
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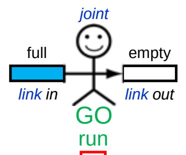
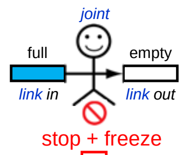
and
GO





WHAT to do:
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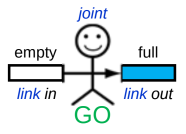
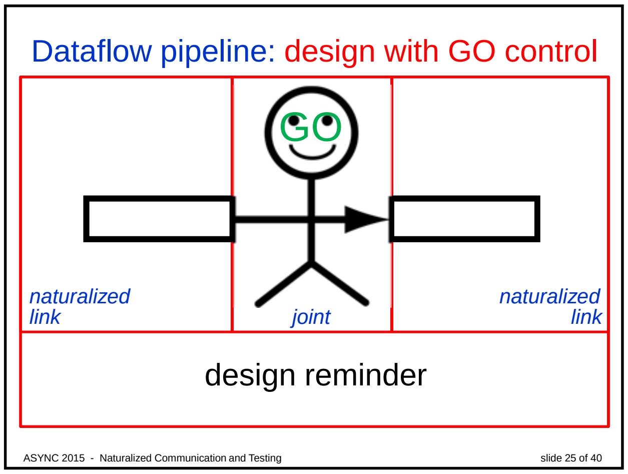


no action



Dataflow pipeline: design with GO control

design reminder

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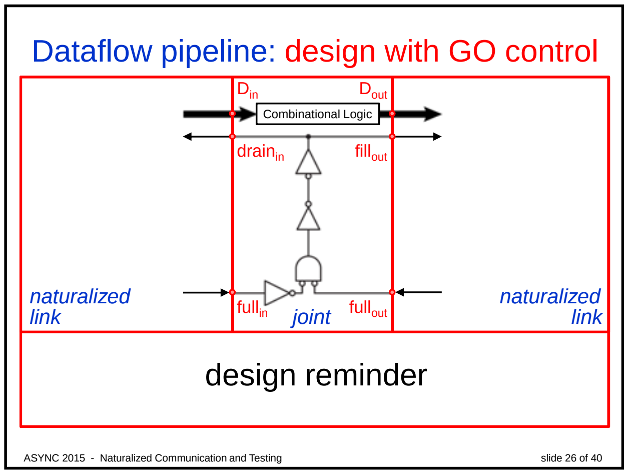

Dataflow pipeline: design with GO control

design reminder

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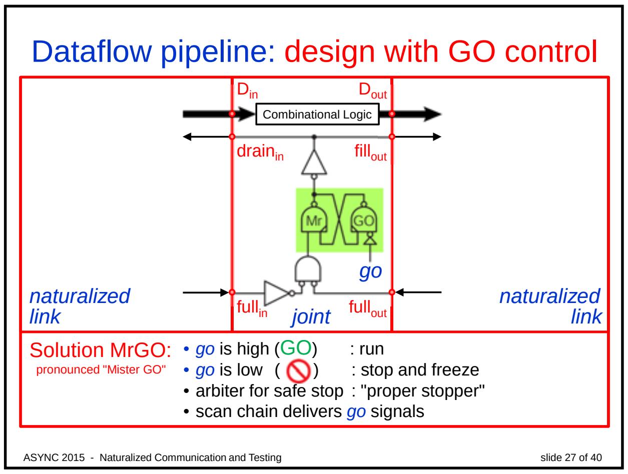

Dataflow pipeline: design with GO control

Solution MrGO:
pronounced "Mister GO"

- *go* is high (GO) : run
- *go* is low (🚫) : stop and freeze
- arbiter for safe stop : "proper stopper"
- scan chain delivers *go* signals

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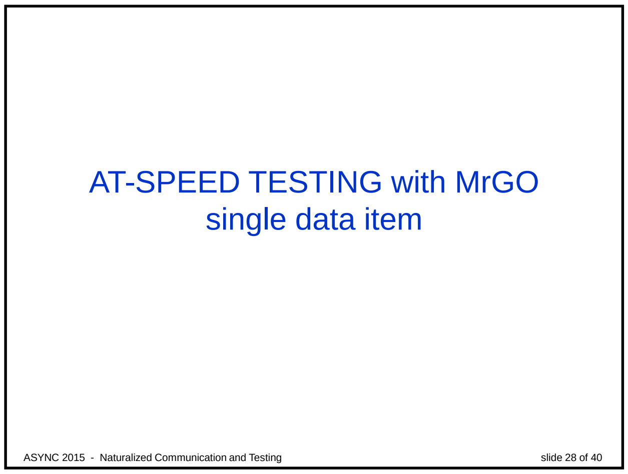

AT-SPEED TESTING with MrGO single data item

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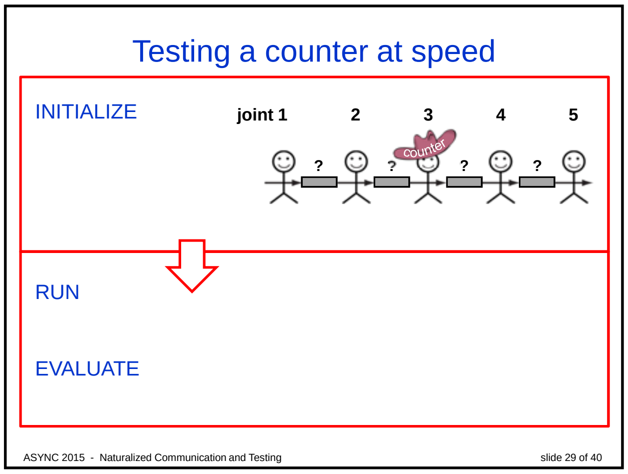

Testing a counter at speed

INITIALIZE

RUN

EVALUATE

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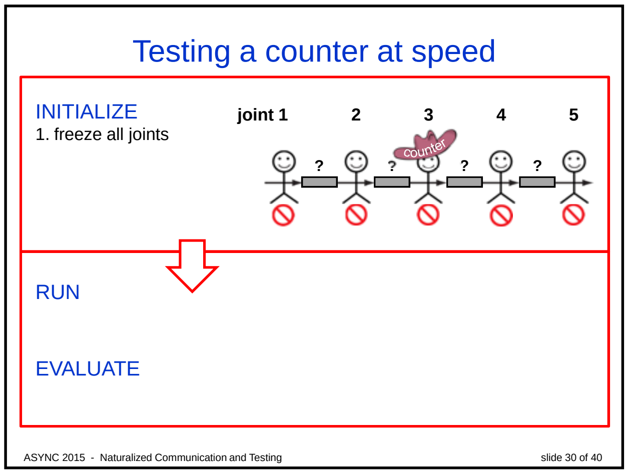

Testing a counter at speed

INITIALIZE
1. freeze all joints

RUN

EVALUATE

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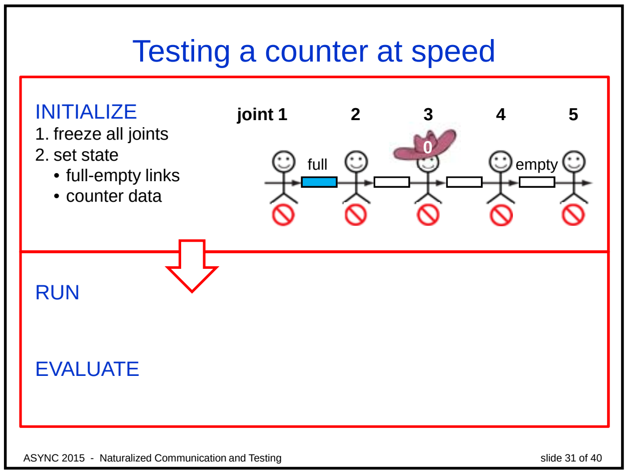
joint 1
2
3
4
5
full
0
empty

Testing a counter at speed

INITIALIZE
1. freeze all joints
2. set state
    • full-empty links
    • counter data

RUN

EVALUATE

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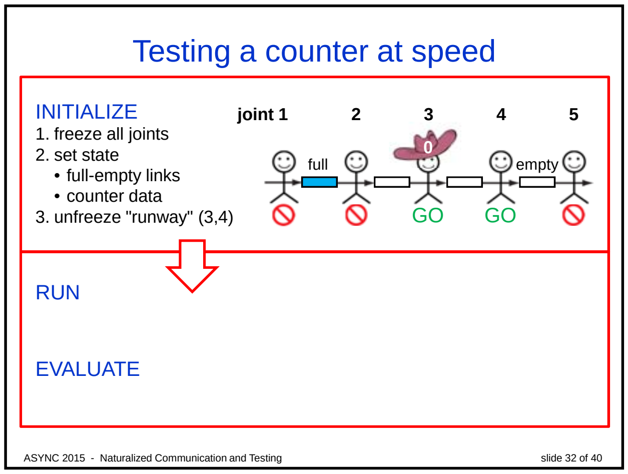
joint 1
2
3
4
5
full
0
empty
GO
GO

Testing a counter at speed

INITIALIZE
1. freeze all joints
2. set state
    • full-empty links
    • counter data
3. unfreeze "runway" (3,4)

RUN

EVALUATE

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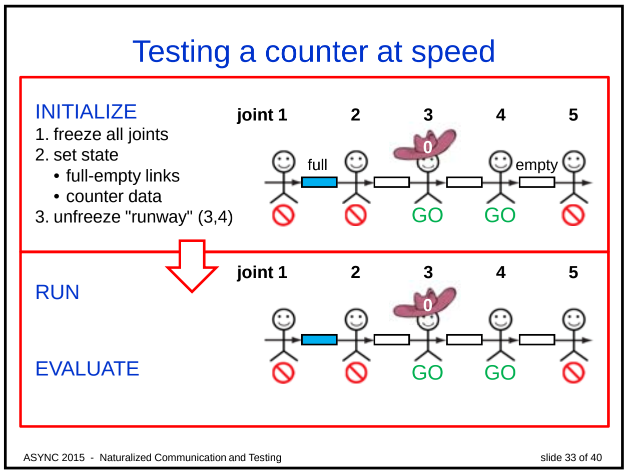
joint 1
2
3
4
5
full
0
empty
GO
GO
joint 1
2
3
4
5
0
GO
GO

Testing a counter at speed

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RUN

EVALUATE

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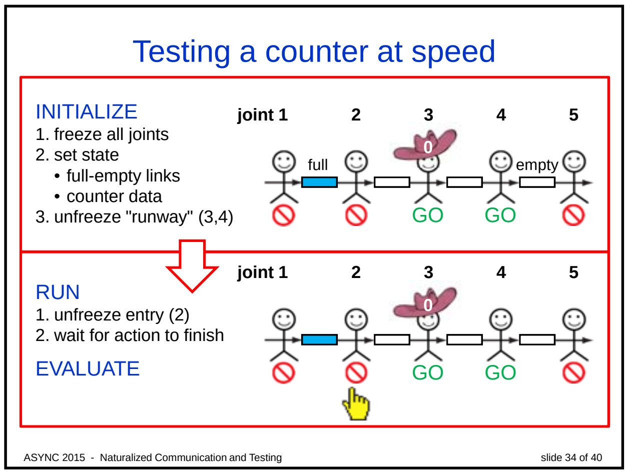
joint 1
2
3
4
5
full
0
empty
GO
GO
joint 1
2
3
4
5
0
GO
GO

Testing a counter at speed

INITIALIZE
1. freeze all joints
2. set state
    • full-empty links
    • counter data
3. unfreeze "runway" (3,4)

RUN
1. unfreeze entry (2)
2. wait for action to finish

EVALUATE

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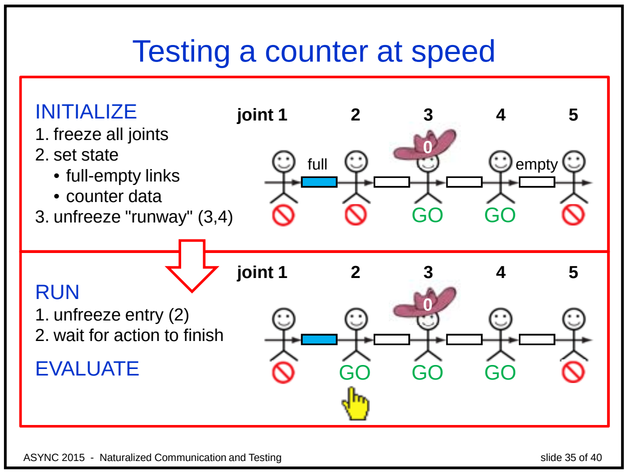
joint 1
2
3
4
5
full
0
empty
GO
GO
joint 1
2
3
4
5
0
GO
GO
GO

Testing a counter at speed

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EVALUATE

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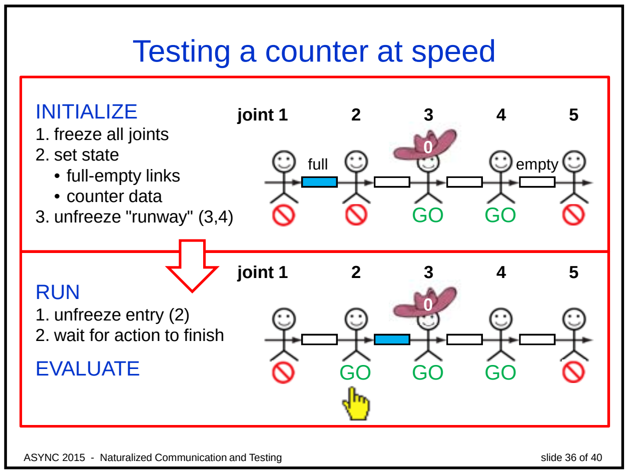
joint 1
2
3
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5
0
GO
GO
GO

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EVALUATE

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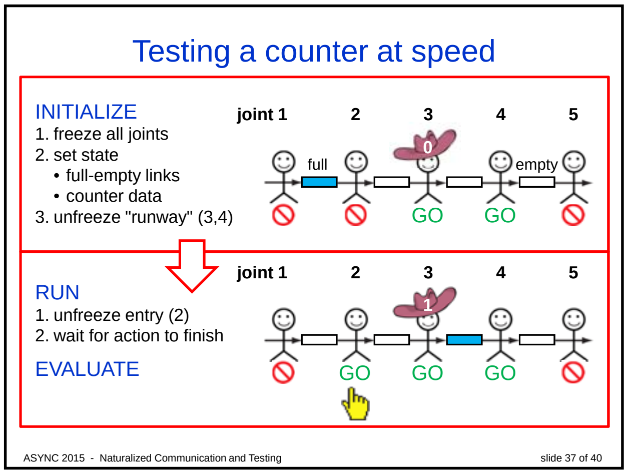

Testing a counter at speed

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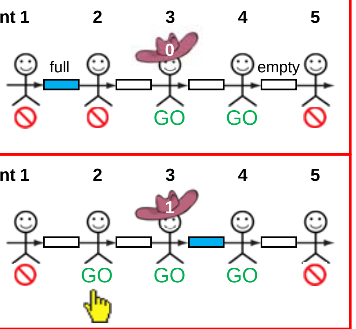
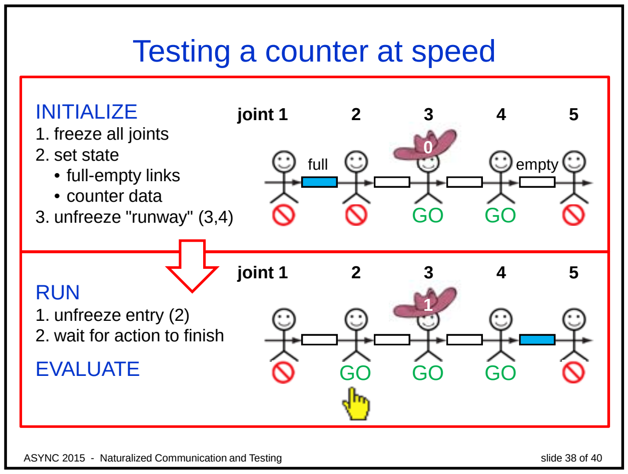
EVALUATE





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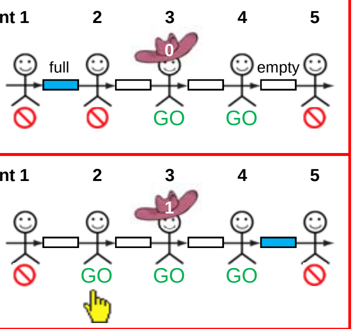
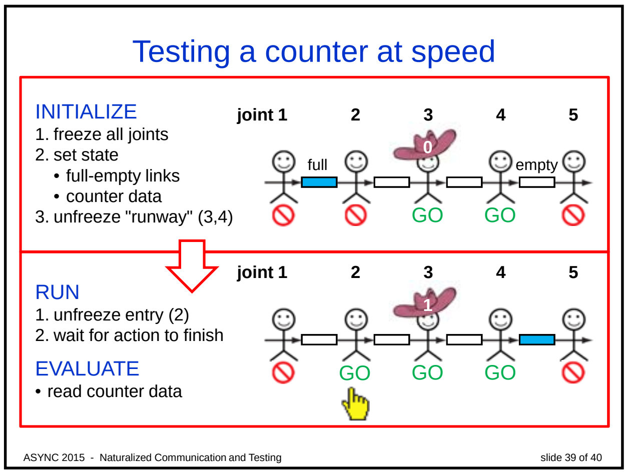
EVALUATE





Testing a counter at speed

INITIALIZE
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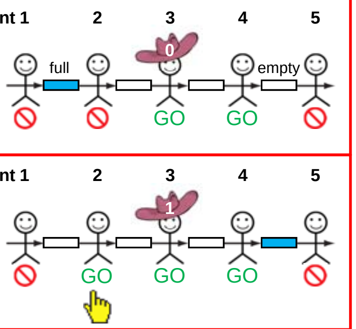
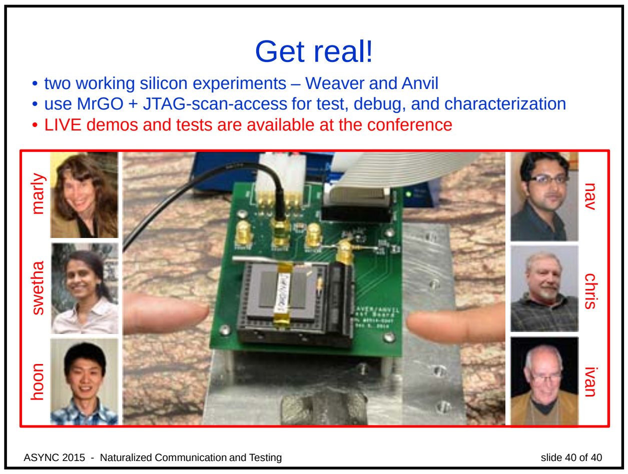
2. set state
   - full-empty links
   - counter data
3. unfreeze "runway" (3,4)

RUN
1. unfreeze entry (2)
2. wait for action to finish

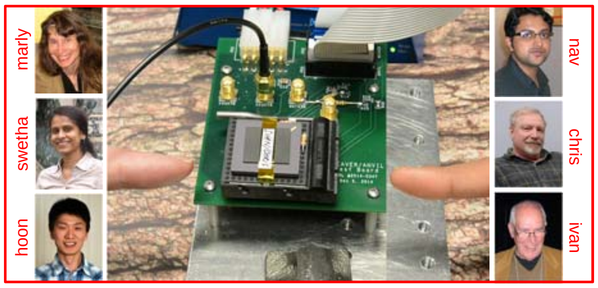
EVALUATE
- read counter data

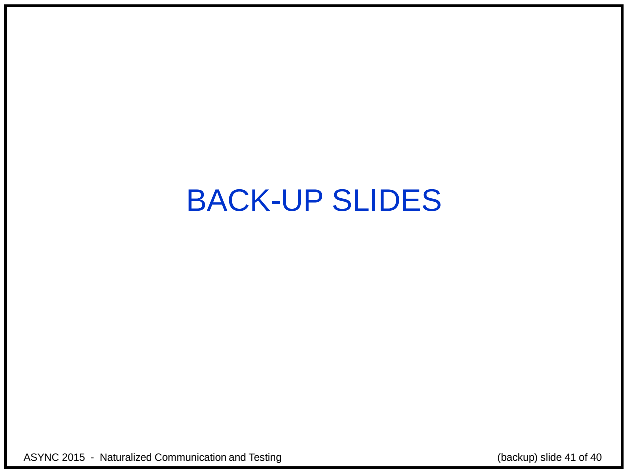




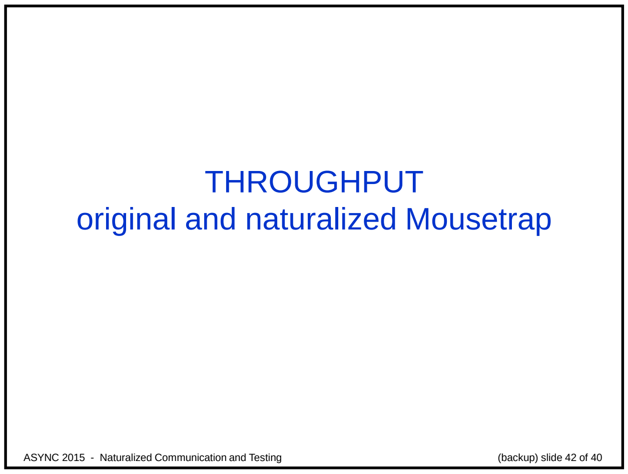
Get real!

- two working silicon experiments – Weaver and Anvil
- use MrGO + JTAG-scan-access for test, debug, and characterization
- LIVE demos and tests are available at the conference



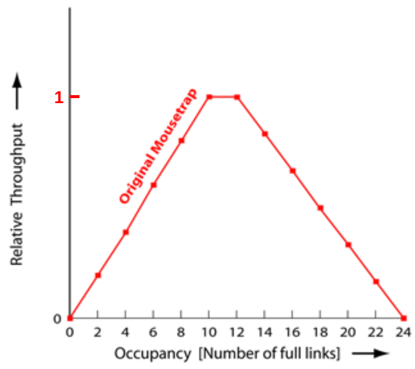


BACK-UP SLIDES

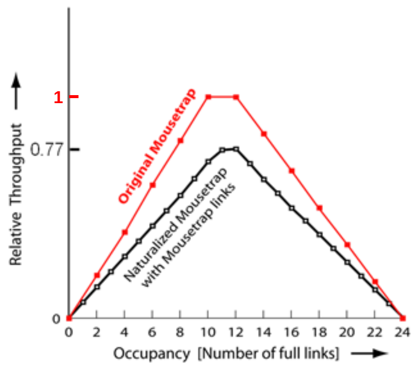


THROUGHPUT
original and naturalized Mousetrap

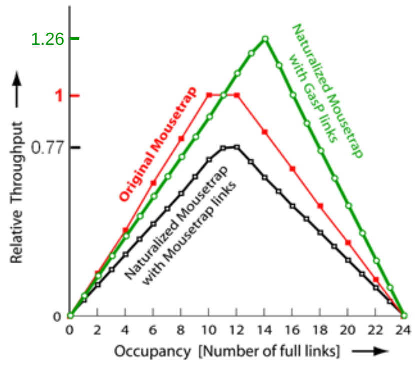
Throughput comparison: canopy graphs



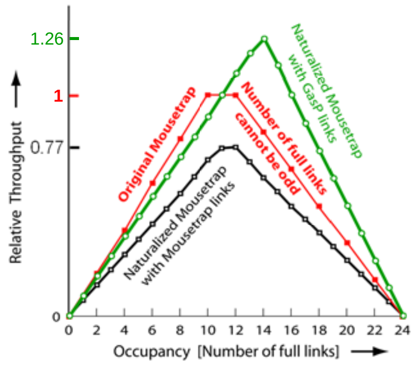
Throughput comparison: canopy graphs



Throughput comparison: canopy graphs



Throughput comparison: canopy graphs



Did You Know

that a ring of original Mousetrap modules cannot possibly hold an odd number of tokens? The same is true for rings of original Micropipeline and Click modules.

The reason is that all three circuit families *fuse together* a forward request and a reverse acknowledge wire.

- To see why odd initialization is impossible start with an empty ring. During initialization, any change in state of a fused wire changes the state of *two* links. The change will either fill one link and drain the other link, fill both links, or drain both links. Each change keeps the number of full links even, and so the number of full links cannot be odd.
- In contrast, naturalized links can be initialized to full or empty independent of and without changing adjacent links.

This little recognized truth appears clearly in Figure 8

- Although all rings have 24 stages, only the two naturalized Mousetrap graphs have sample points for all occupancies.
- The center graph for original Mousetrap can plot throughput only for even link occupancy, offering fewer sample points.

Naturalized communication
restores the generality
lost to the original circuit families

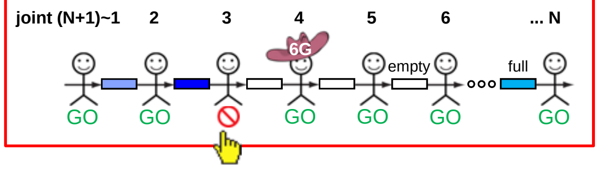
DELETE-button
added especially
for Jens Sparsø

CANOPY GRAPHS
characterization with MrGO

Creating canopy graphs

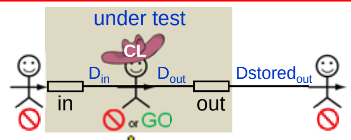
```
DO (ALL > i > 0 links)
   counter=0
   run 1 second with i full links
   arbitrated stop
   read counter
OD
```

FINAL for *i* ~ 60% links



STUCK-AT FAULTS
one-shot testing with MrGO

Testing stuck-at faults



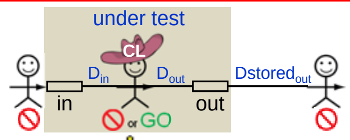
TEST control logic

```
DO (ALL full-empty link combos)
   freeze joint
   set $full_{in}$  = combo(in)
       $full_{out}$ = combo(out)
   evaluate if links remain unchanged
   unfreeze joint
   evaluate final link states
OD
```

TEST datapath (normally opaque)

```
DO (ALL CL test inputs)
   freeze joint
   set $full_{in}$       = TRUE
       $full_{out}$      = FALSE
       $D_{in}$          = test input
       $Dstored_{out}$ = $\neg CL(D_{in})$
   evaluate if $Dstored_{out}$ remain unchanged
   unfreeze joint
   evaluate if $Dstored_{out}$ = $CL(D_{in})$
OD
```

Testing stuck-at faults



TEST control logic

```
DO (ALL full-empty link combos)
   freeze joint
   set $full_{in}$  = combo(in)
       $full_{out}$ = combo(out)
   evaluate if links remain unchanged
   unfreeze joint
   evaluate final link states
OD
```

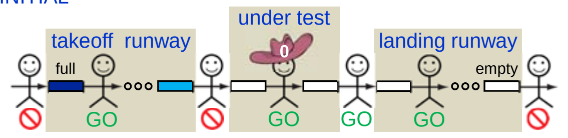
TEST datapath (normally transparent)

```
DO (ALL CL test inputs)
   freeze joint
   set $full_{in}$=$full_{out}$ = TRUE
       $D_{in}$            = test input
       $Dstored_{out}$ = $\neg CL(D_{in})$
   evaluate if $Dstored_{out}$ remain unchanged
   set $full_{out}$ = FALSE
   unfreeze joint
   evaluate if $Dstored_{out}$ = $CL(D_{in})$
OD
```

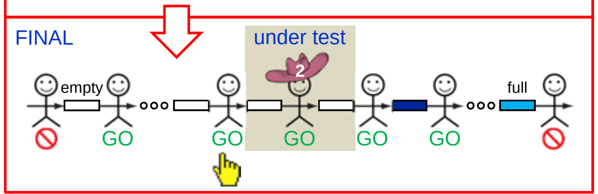
AT-SPEED TESTING
of data burst with MrGO

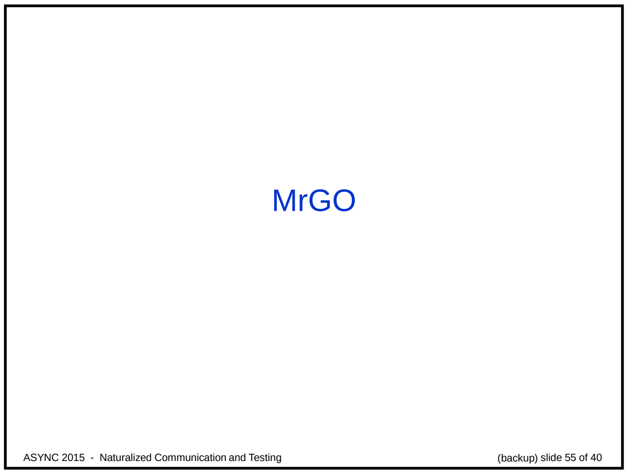
Testing a burst of data at speed

INITIAL



FINAL





MrGO

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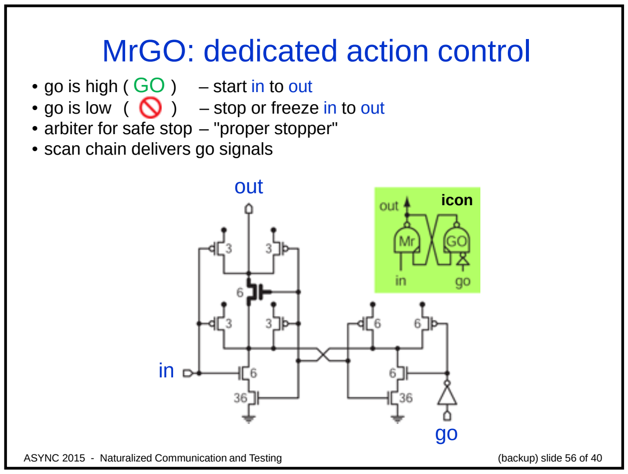
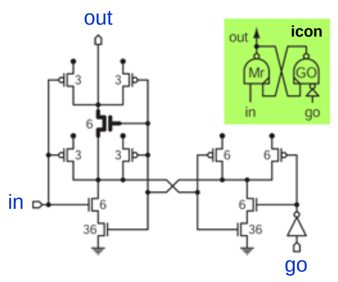


MrGO: dedicated action control

- go is high (GO) – start in to out
- go is low (🚫) – stop or freeze in to out
- arbiter for safe stop – "proper stopper"
- scan chain delivers go signals



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