Generation of Inductive Invariants from Register Transfer Level Designs of Communication Fabrics

Sebastiaan J.C. Joosten
Julien Schmaltz

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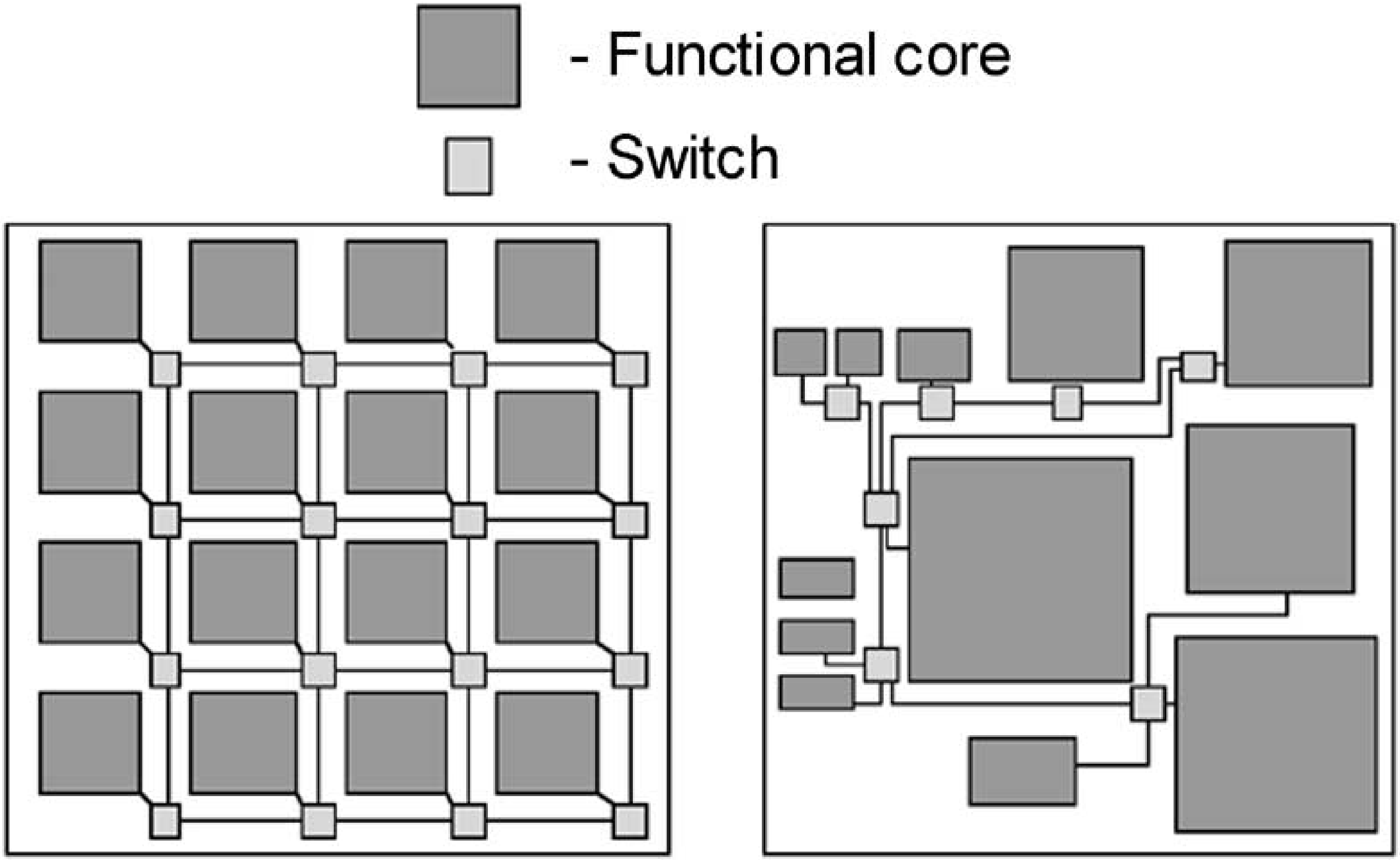

Image: *Testing Network-on-Chip Communication Fabrics*
Cristian Grecu, Resve Saleh

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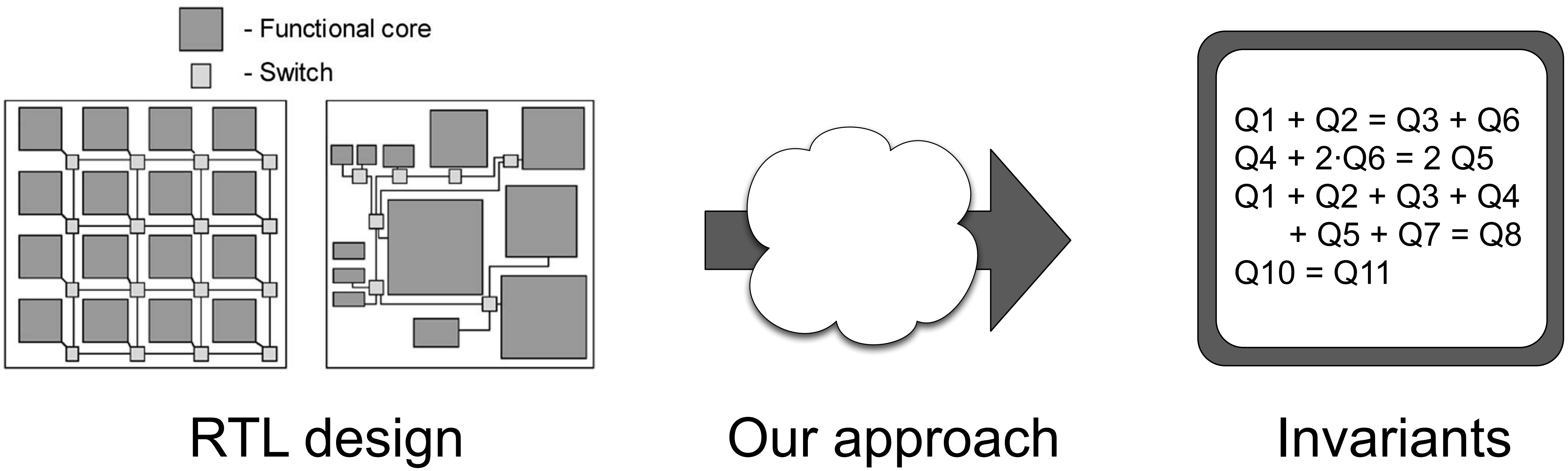

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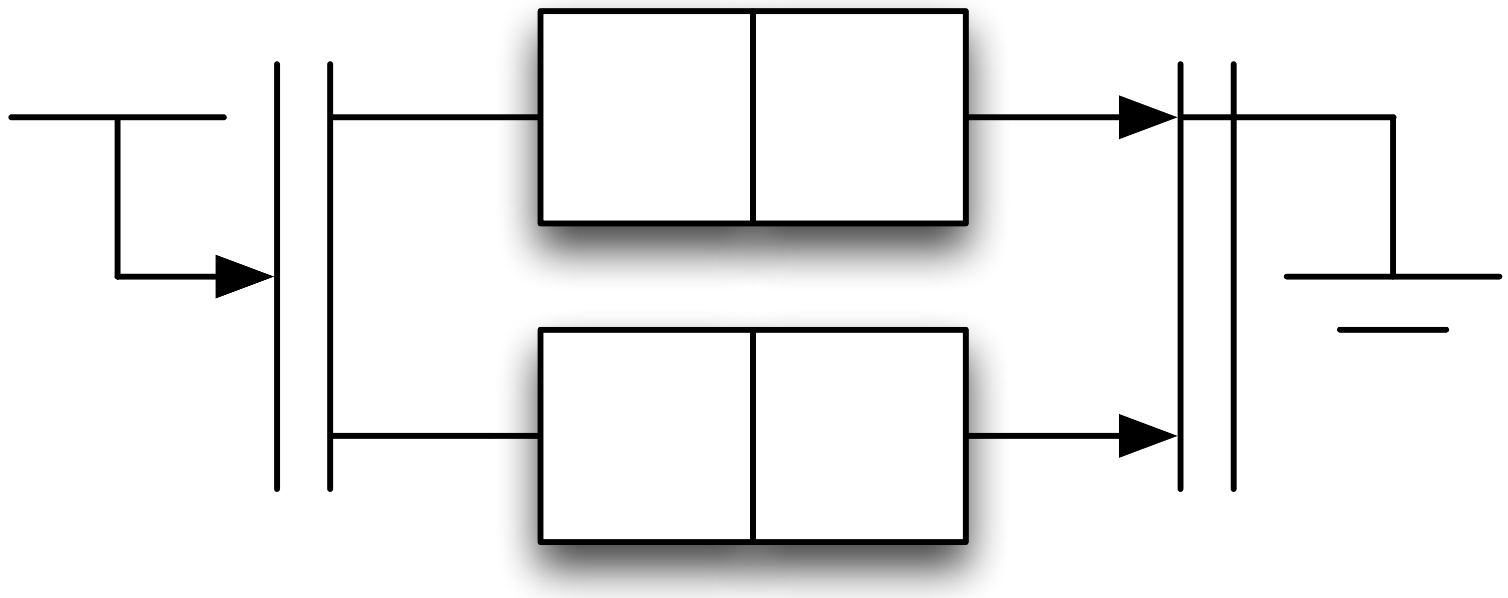

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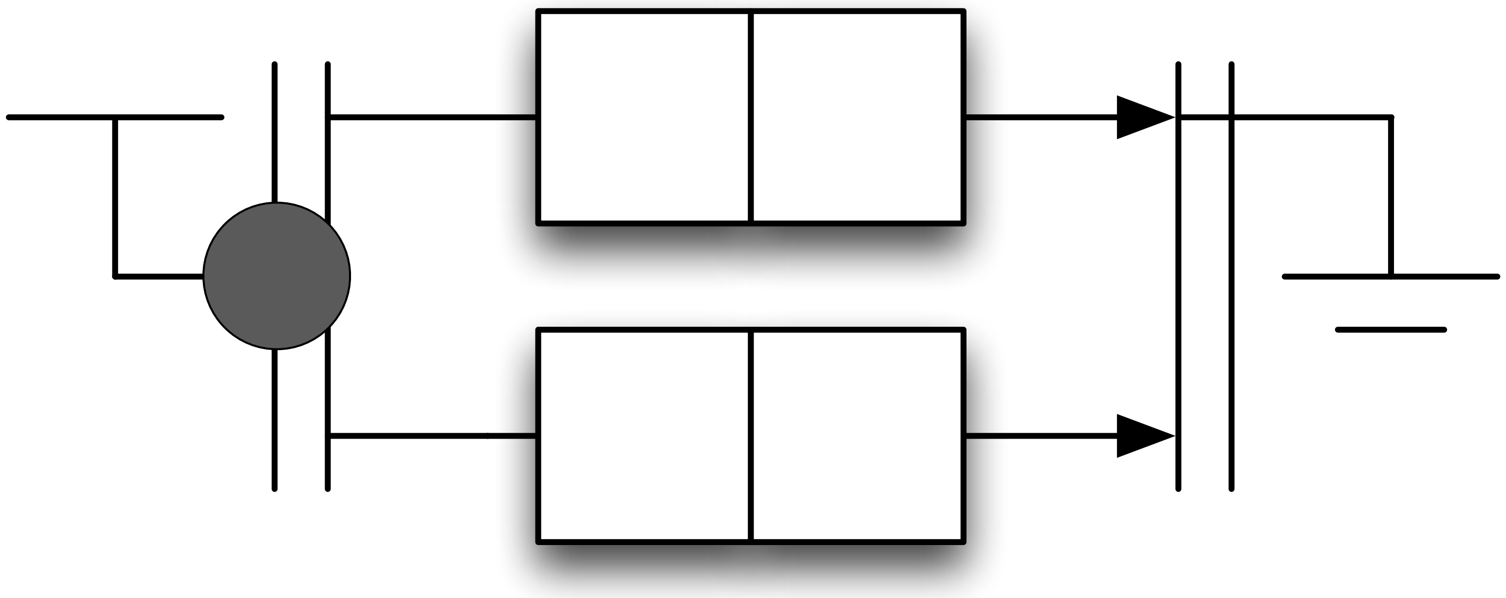

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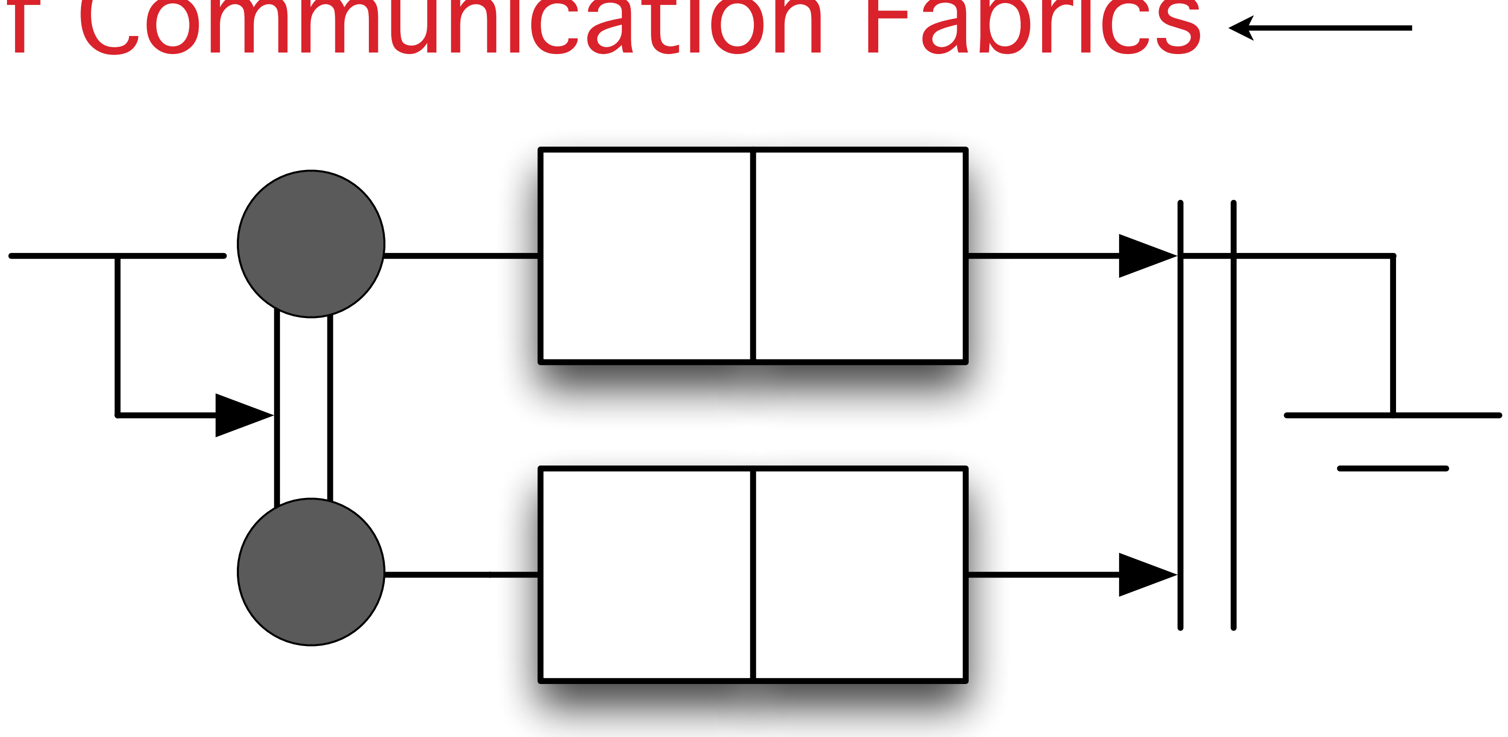

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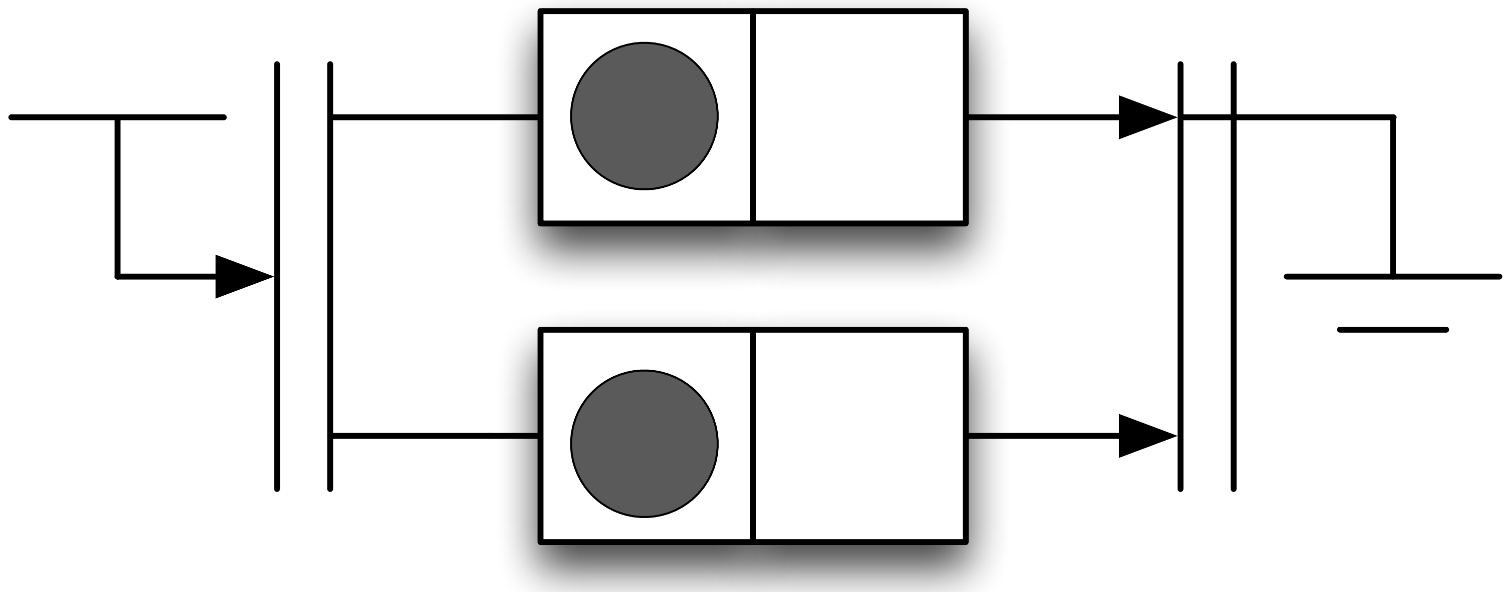

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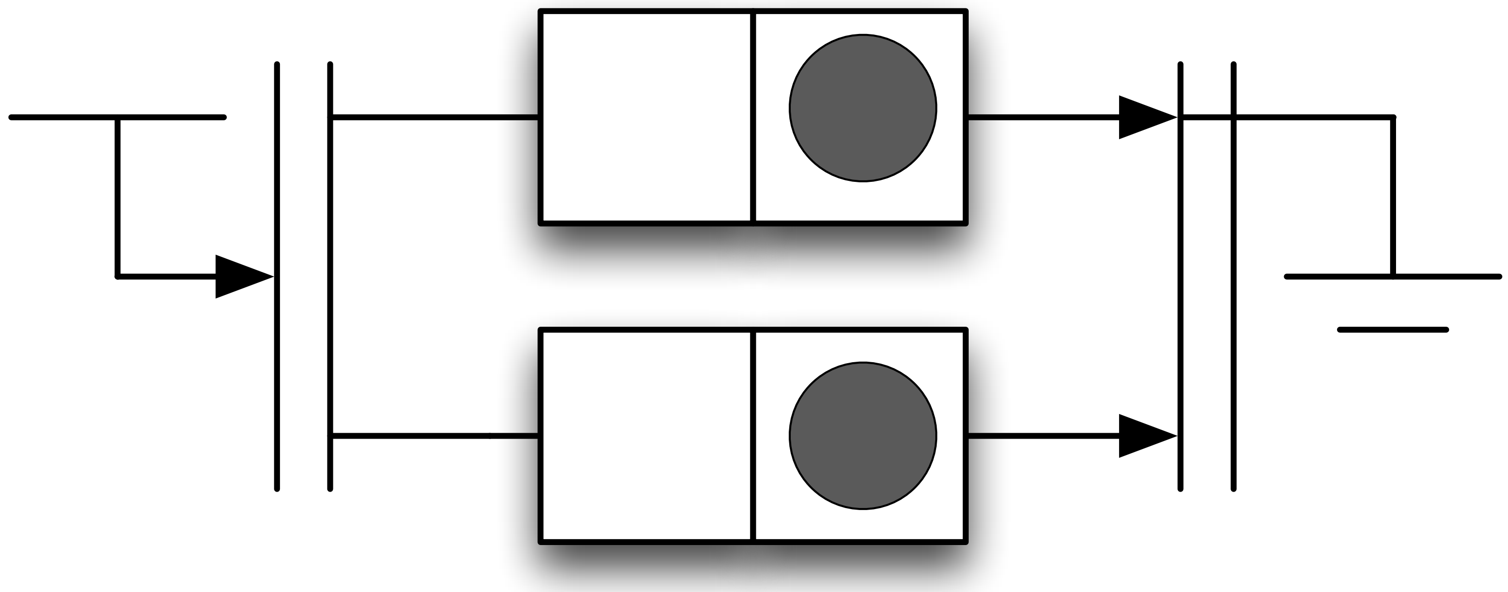

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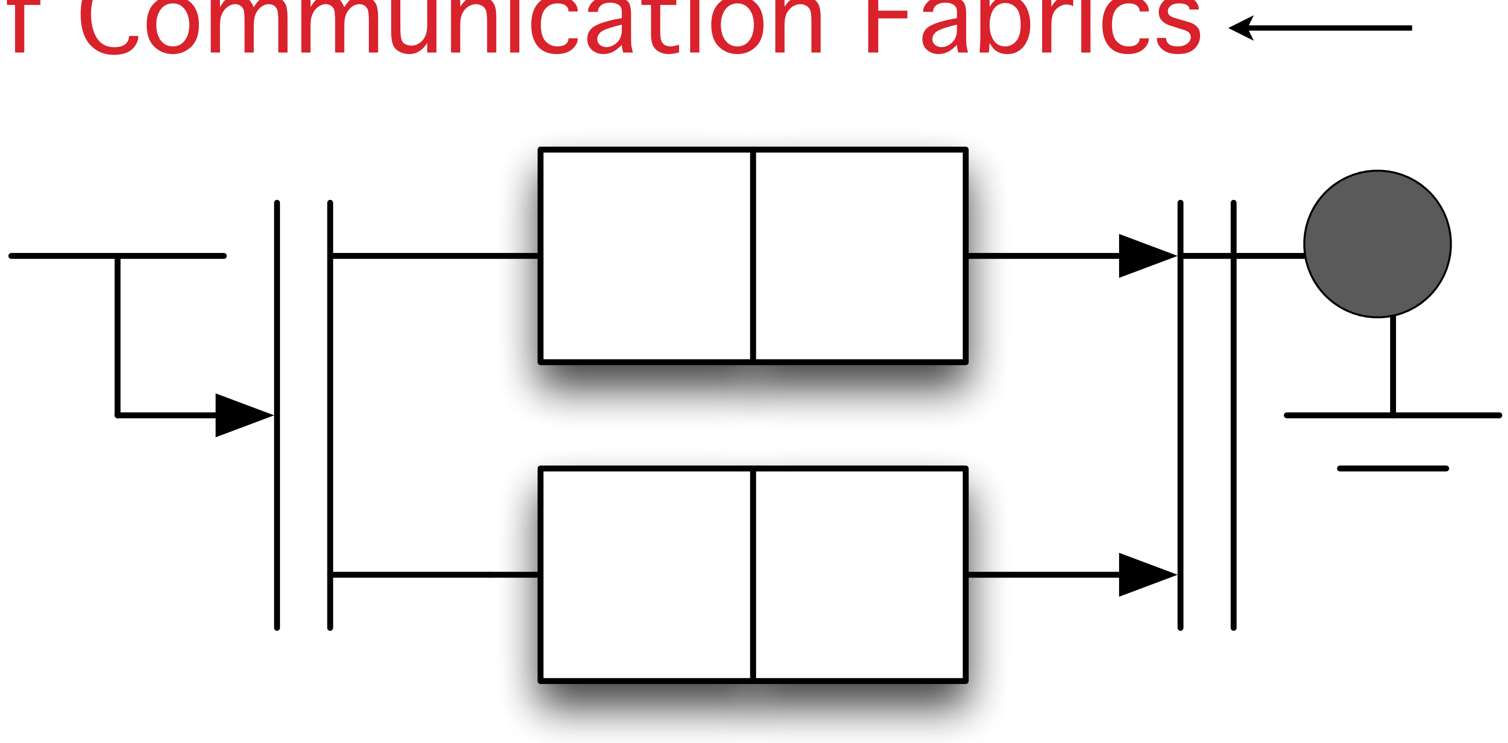

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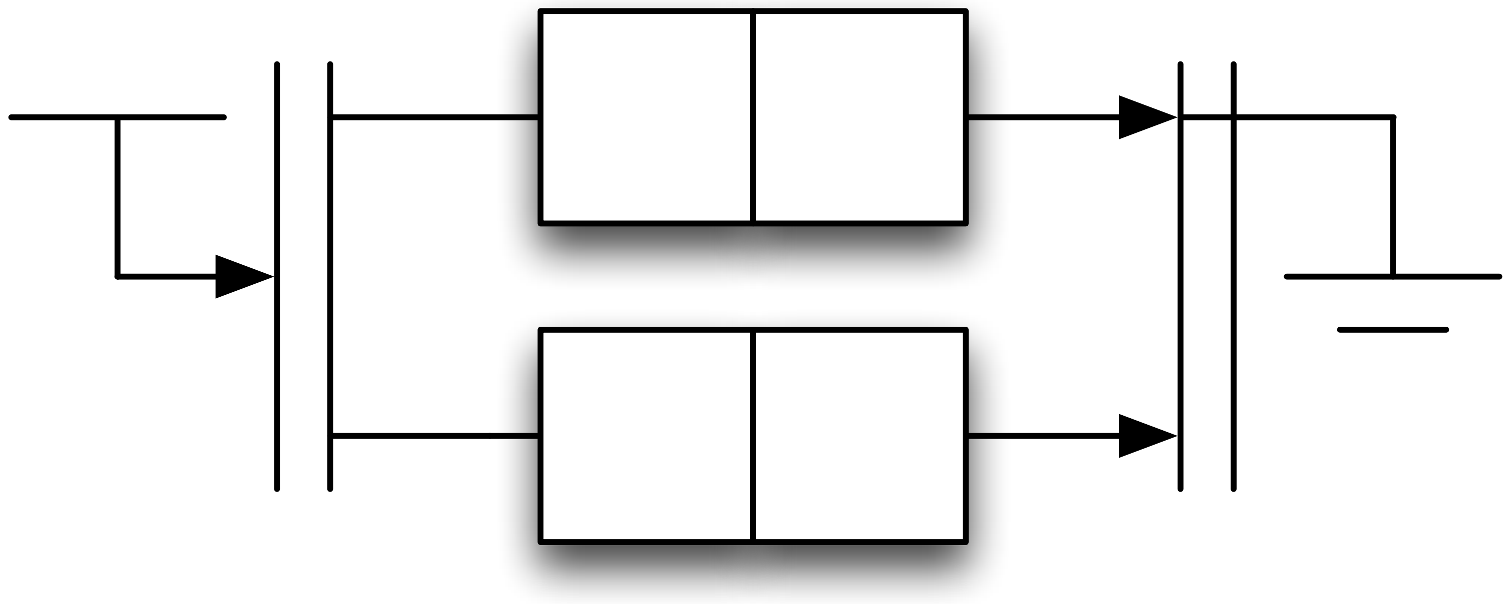

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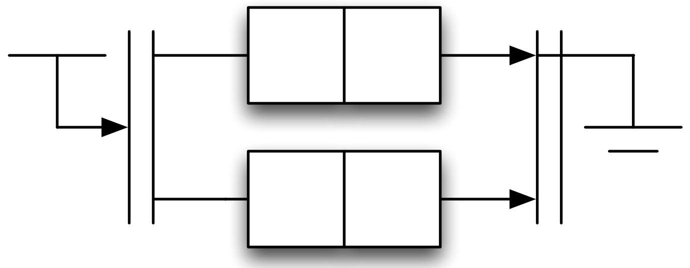

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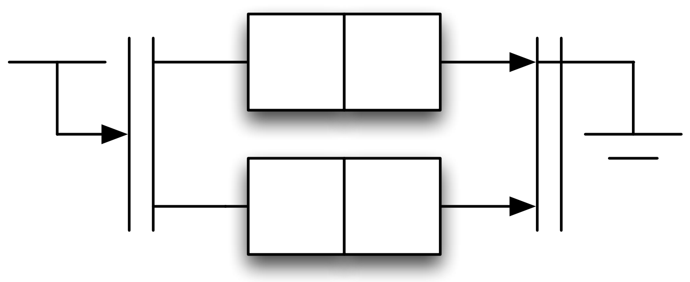

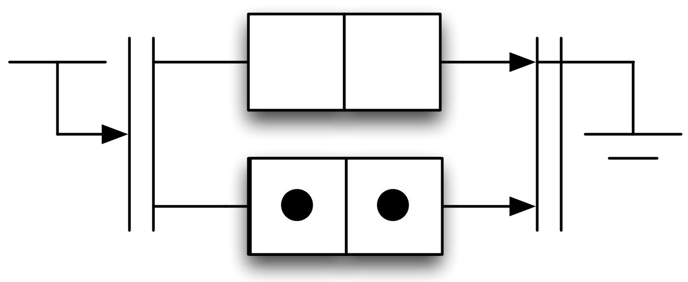

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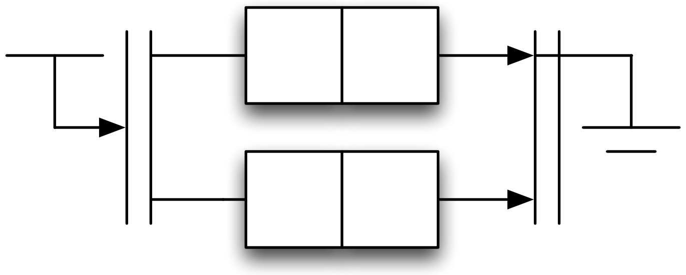
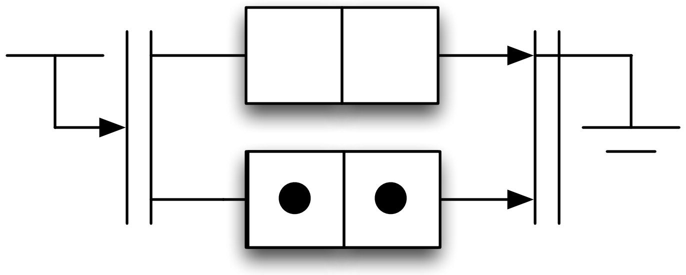
Generation of Inductive Invariants ⟵ from Register Transfer Level Designs of Communication Fabrics





Is this configuration reachable?

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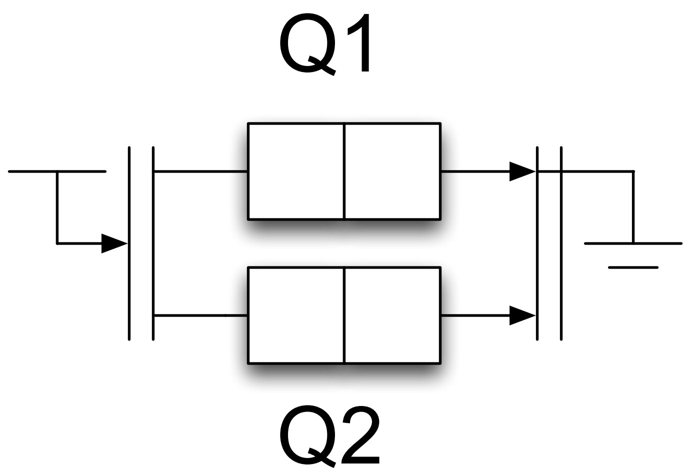

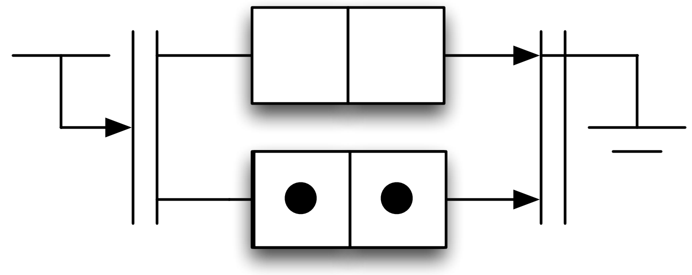

Violates #Q1 = #Q2

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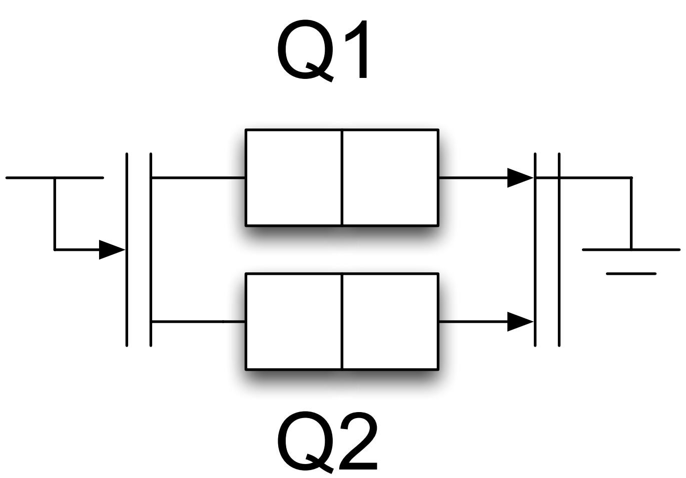
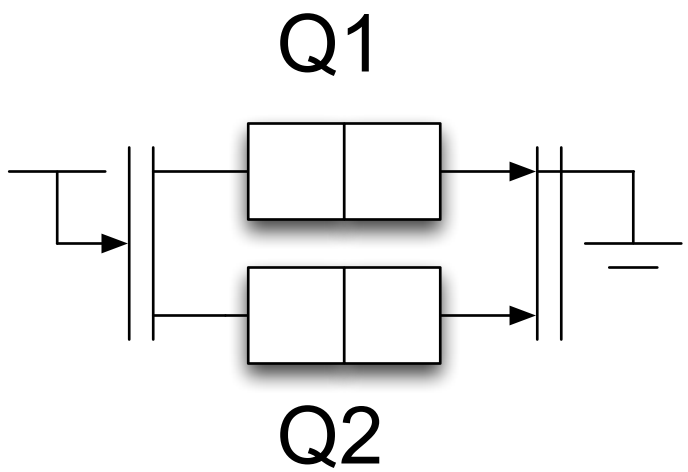


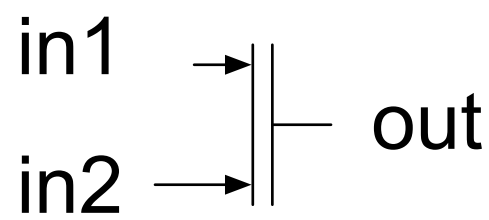
$Q1\_in = Q2\_in$
$Q1\_out = Q2\_out$
$\Delta Q1 = Q1\_in - Q1\_out$
$\Delta Q2 = Q2\_in - Q2\_out$

$\Delta Q1 = \Delta Q2$ so
$\#Q1 = \#Q2$

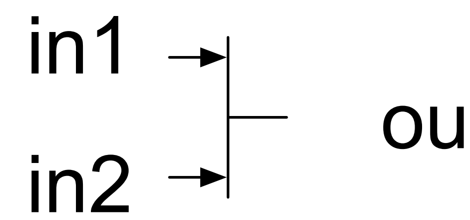
Satrajit Chatterjee, Michael Kishinevsky, Automatic Generation of Inductive Invariants from High-Level Microarchitectural Models of Communication Fabrics, CAV'10, LNCS vol 6174

Generation of Inductive Invariants ← from Register Transfer Level Designs of Communication Fabrics





in1 = in2 = out



in1 + in2 = out

Satrajit Chatterjee, Michael Kishinevsky, Automatic Generation of Inductive Invariants from High-Level Microarchitectural Models of Communication Fabrics, CAV'10, LNCS vol 6174

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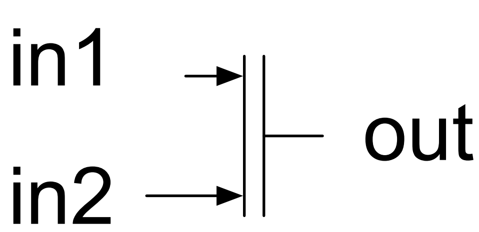
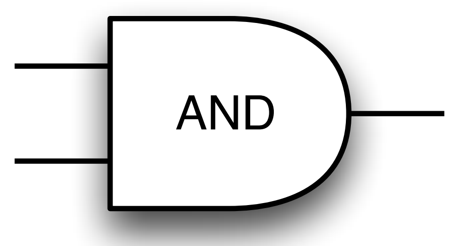
Generation of Inductive Invariants from Register Transfer Level Designs of Communication Fabrics

- Find (all?) linear equalities
- Verifying “Q1_in = Q2_in” is equivalent to UNSAT
- (co)NP-hard in theory





in1 = in2 = out

???

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Observation

- The set of conjunctions of independent wires is a linearly independent set (Interpret High as 1, Low as 0)

	A	B	AB
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Observation

- The set of conjunctions of independent wires is a linearly independent set (Interpret High as 1, Low as 0)

	A	B	AB	A+B	A | B
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	0	1	1
1	1	1	1	2	1

Translating RTL to a Linear System

- $A \mathbin{\&} B \rightarrow AB$
- $A \mid B \rightarrow A + B - AB$
- $A \text{ XOR } B \rightarrow A + B - 2 \cdot AB$
- $\neg A \rightarrow T - A$ T *for True*
- $A \mathbin{\&} (B \mid \neg A) \rightarrow A \mathbin{\&} (B \mid (T - A))$

$$\rightarrow A(B + (T - A) - B(T - A))$$
$$= AB + AT - AA - ABT + ABA$$
$$= AB + A - A - AB + AB$$
$$= AB$$

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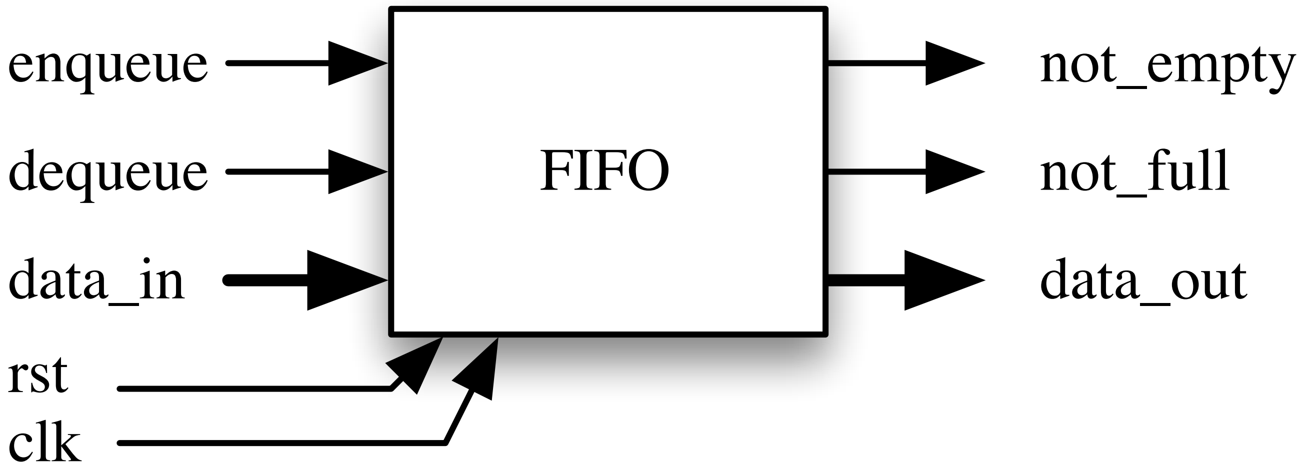
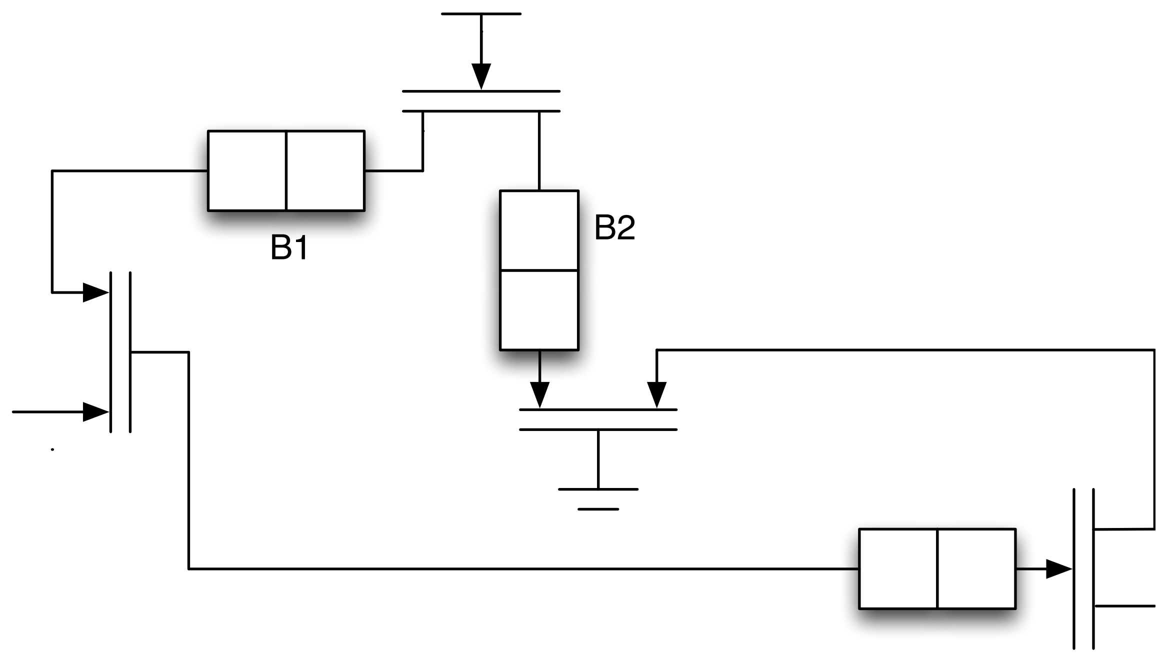
Obtaining invariants from the linear system



enter = (enqueue & not_full)
exit = (dequeue & not_empty)
Δ FIFO = enter - exit

- One such equation per buffer
- Extra equations for data dependencies
- Equations over linearly independent variables
→ all linear dependencies of buffers are found

Experimental results



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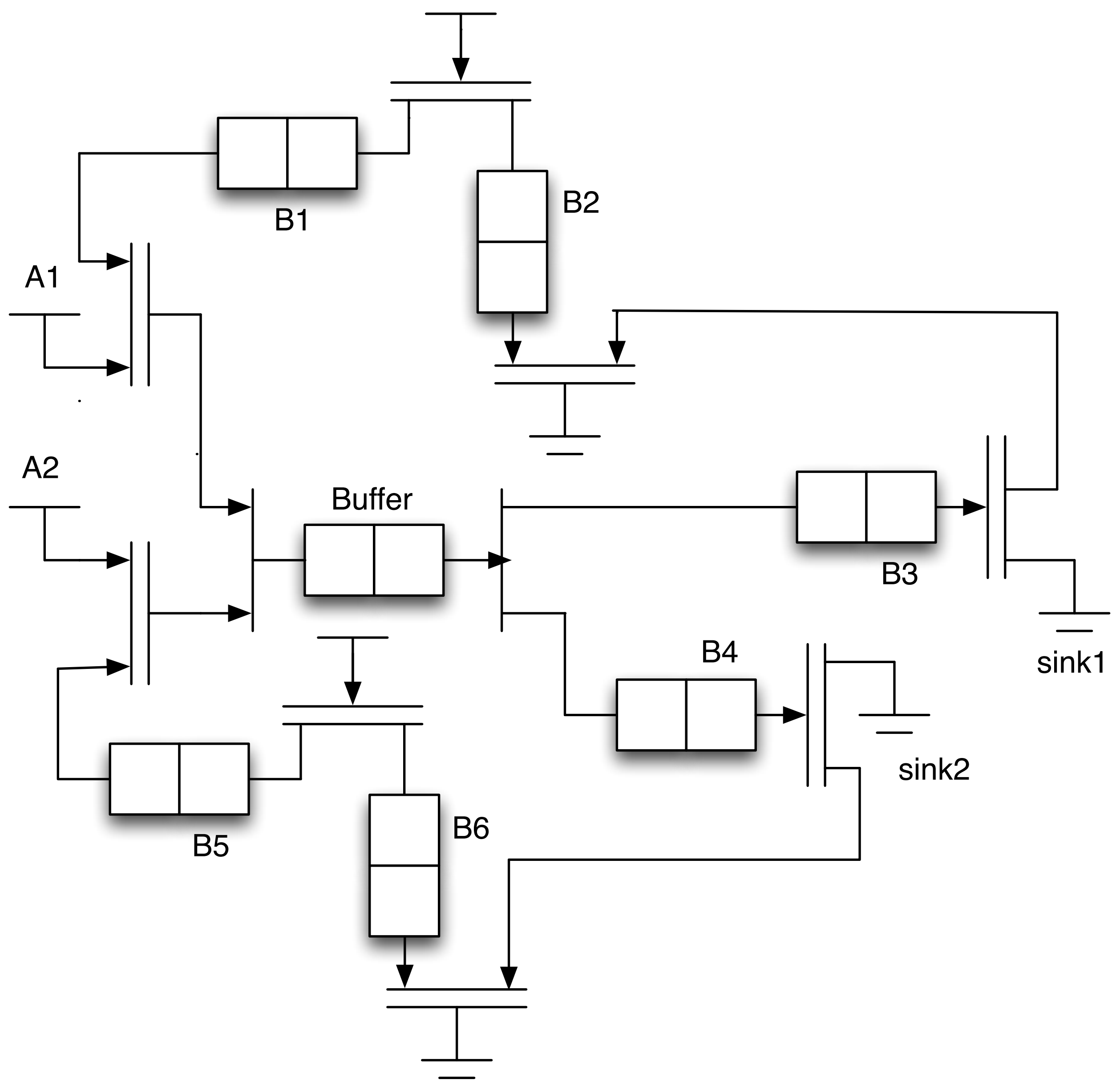
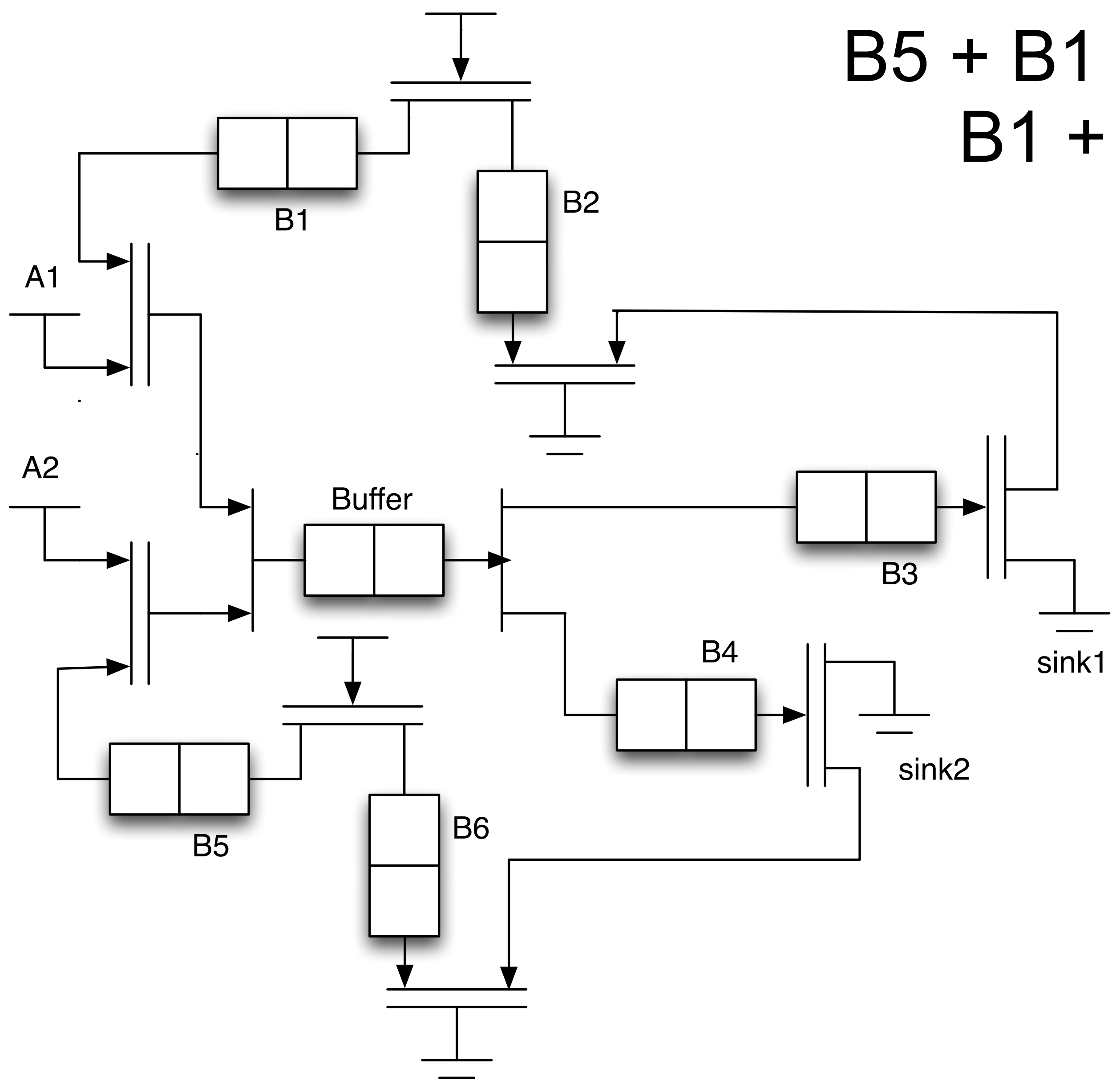
Experimental results



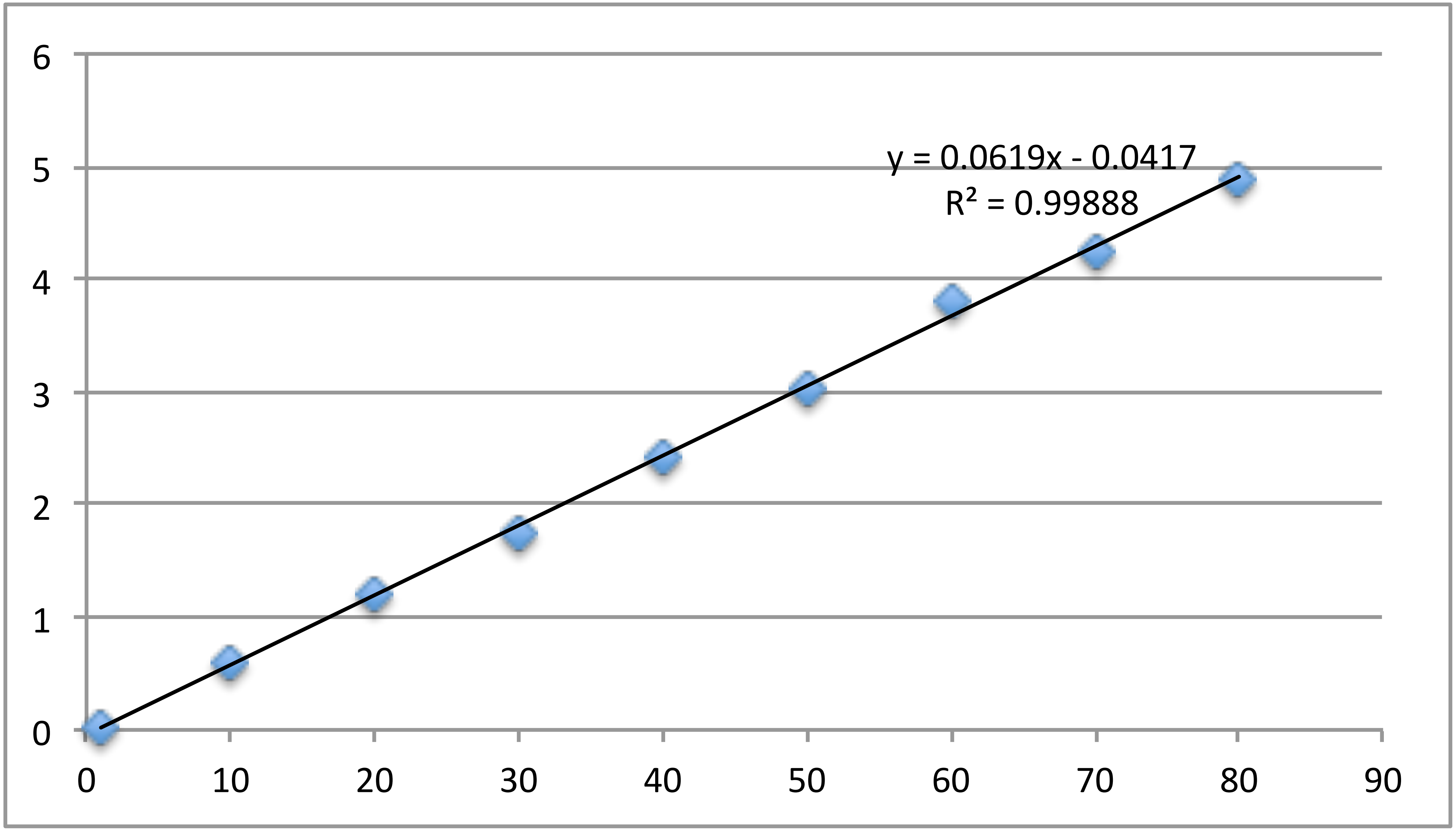
Experimental results



B5 + B1 + Buffer + B3 + B4 - B2 - B6 = 0

B1 + Buffer + B3 - B2 - Buffer_[3] = 0

Experimental results



- http://genoc.cs.ru.nl/

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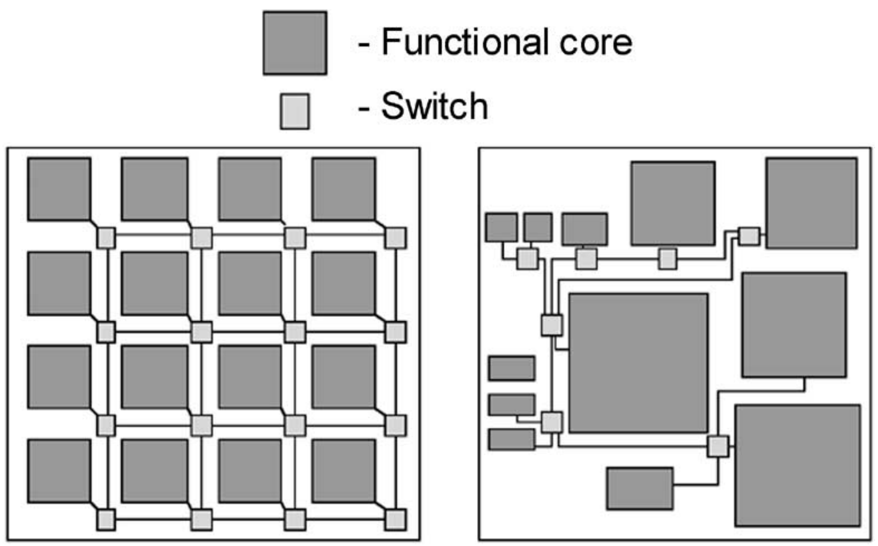
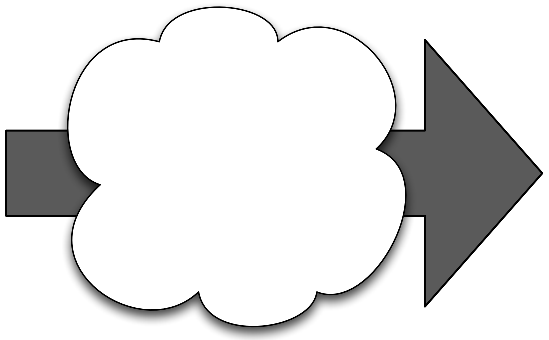
Contributions



RTL design



Our approach

Q1 + Q2 = Q3 + Q6
Q4 + 2·Q6 = 2 Q5
Q1 + Q2 + Q3 + Q4
+ Q5 + Q7 = Q8
Q10 = Q11

Invariants