Sunflow

Efficient Optical Circuit Scheduling for Coflows

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This Work

- Optical Circuit Switching has many **advantages** over packet switching.

- **Disadvantage**: usually worse traffic performance.

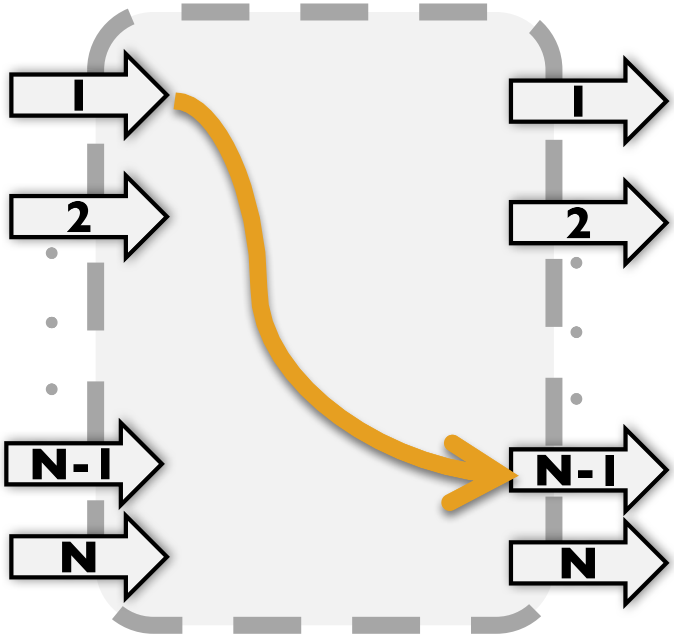
- **Sunflow** overcomes disadvantage with **efficient circuit scheduling**.

Optical Circuit Switch v.s. Electrical Packet Switch

	Optical Circuit Switch (OCS)	Electrical Packet Switch (EPS)	OCS better?
Traffic processing	No packet processing	Store and forward EACH packet	**Energy efficiency**
Bandwidth upgrade	Reuse old	Buy new	**Future proof, cost efficiency**
Switching speed			

Op Switch v.s. E et Switch

Optical Circuit Switch



Send at “link rate”, up to **10s of ms switching delay**

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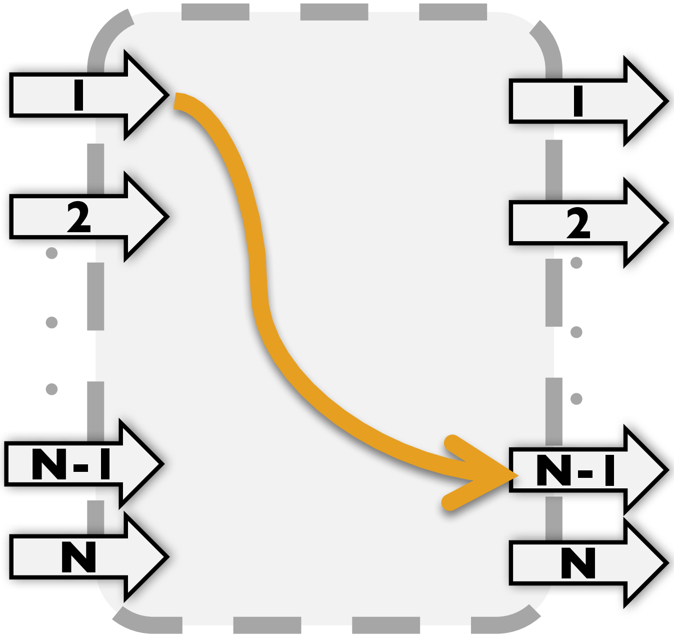
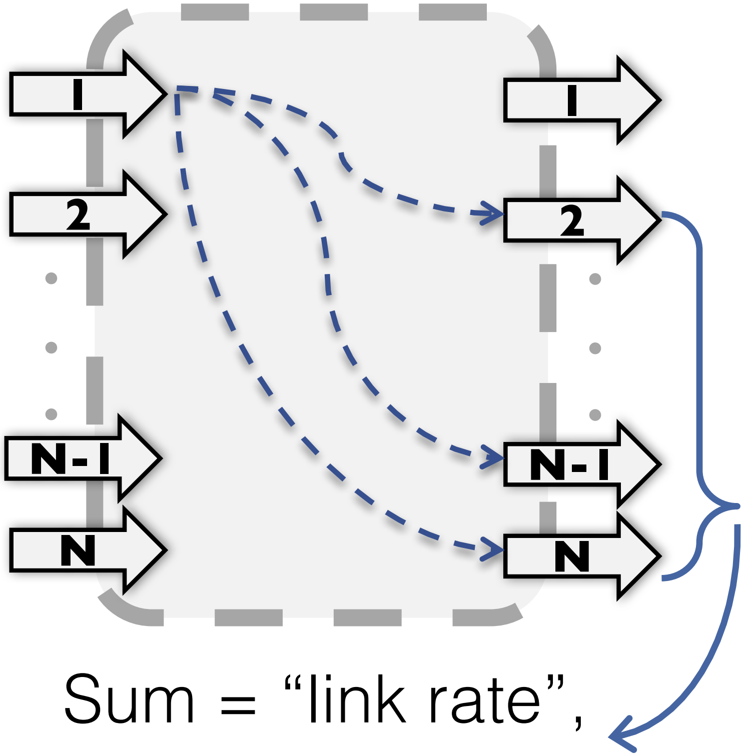
Optical Circuit Switch



Send at “link rate”, up to **10s of ms switching delay**

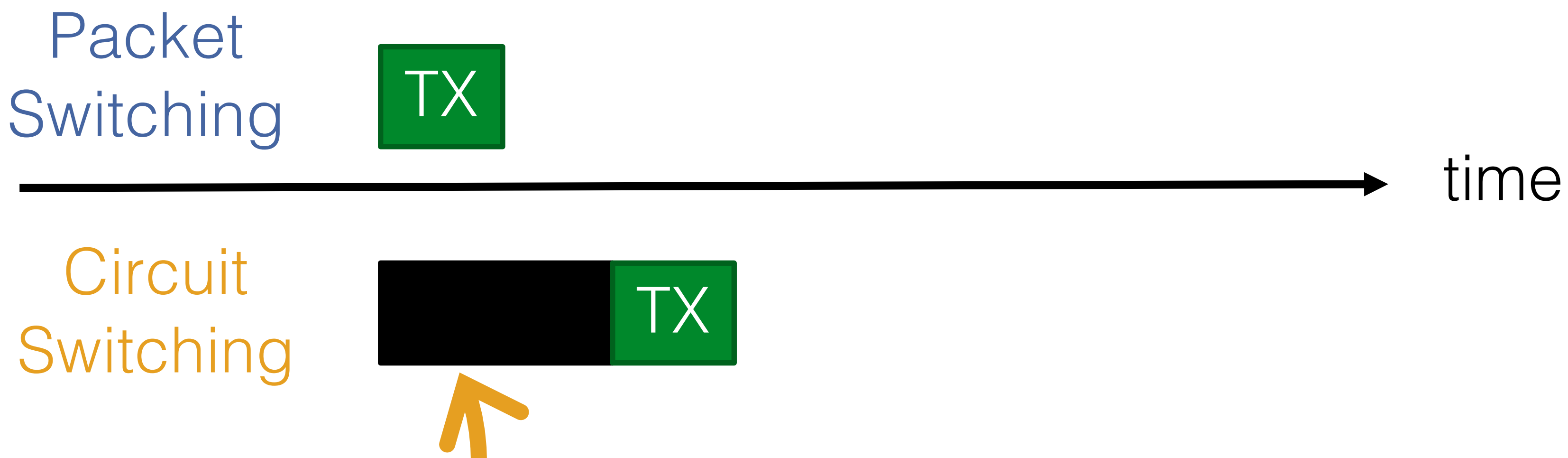
Electrical Packet Switch



Sum = “link rate”, fast switching.

Optical Circuit Switch v.s. Electrical Packet Switch

	Optical Circuit Switch (OCS)	**Electrical Packet Switch (EPS)**	**OCS better?**
Traffic processing	No packet processing	Store and forward EACH packet	**Energy efficiency**
Bandwidth upgrade	Reuse old	Buy new	**Future proof, cost efficiency**
Switching speed	Setting up a circuit up to 10s of ms	Packet granularity 10s of ns	**Traffic delay**



Due to circuit switching delay, the performance of circuit switching is usually **worse** than packet switching for **small data.**

Packet Switching

Performance

Circuit Switching

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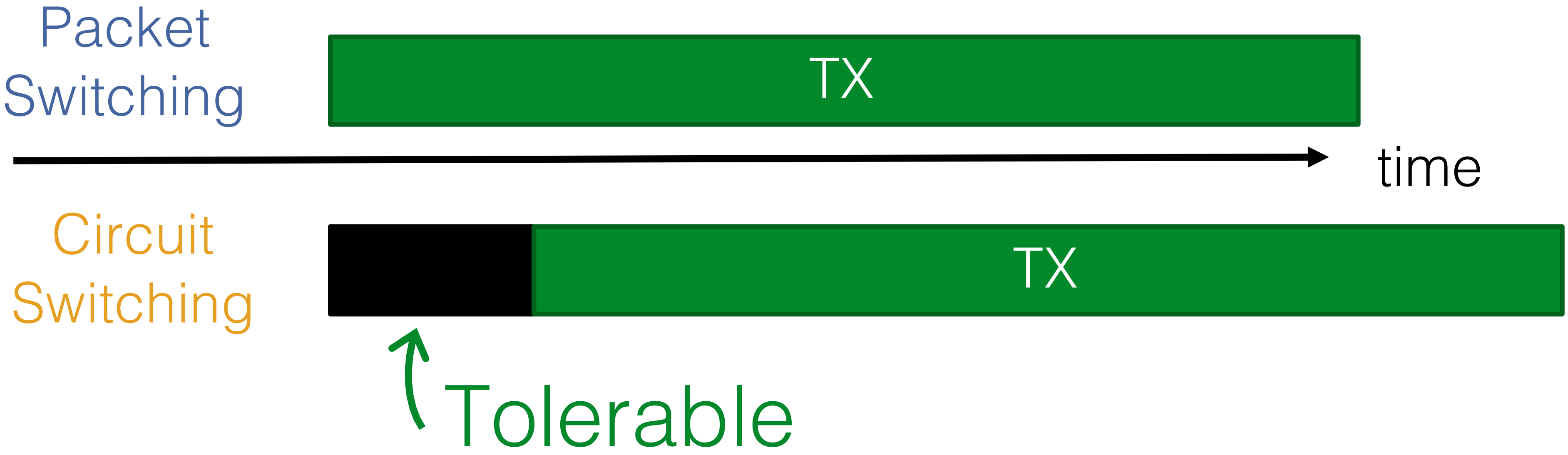
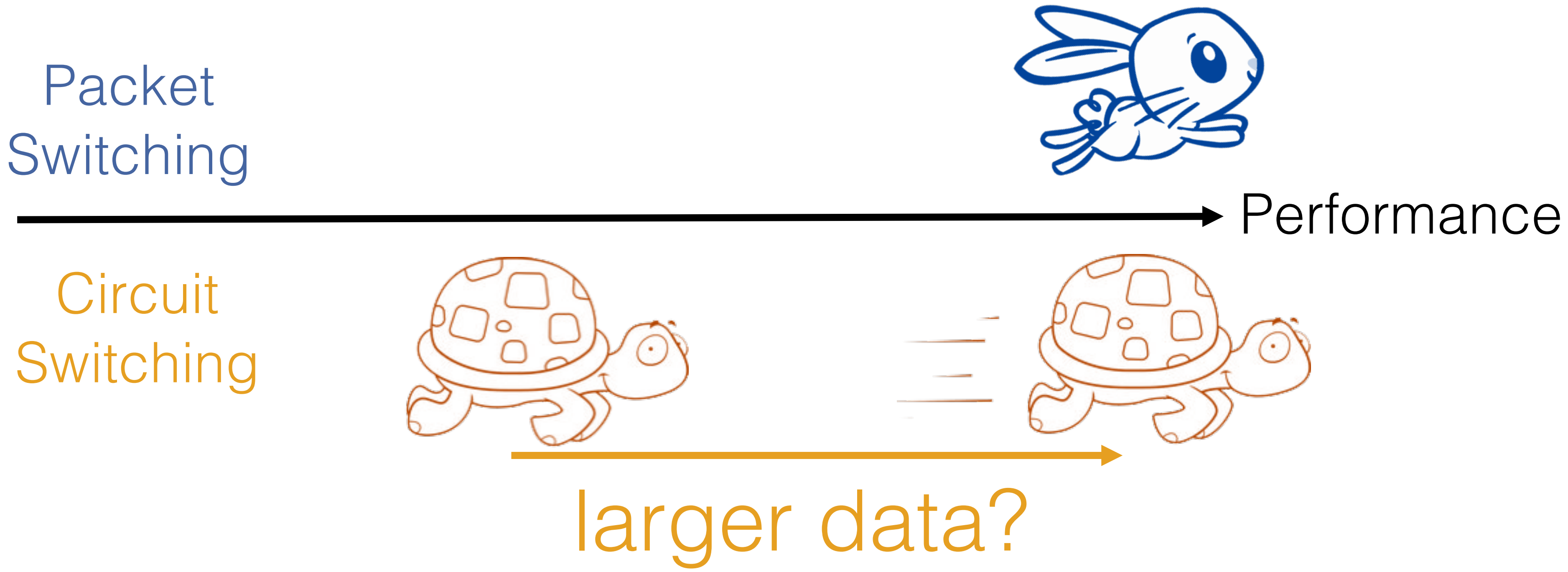


For **larger data**, performance of circuit switching may become **closer** to packet switching.



Packet Switching

Performance

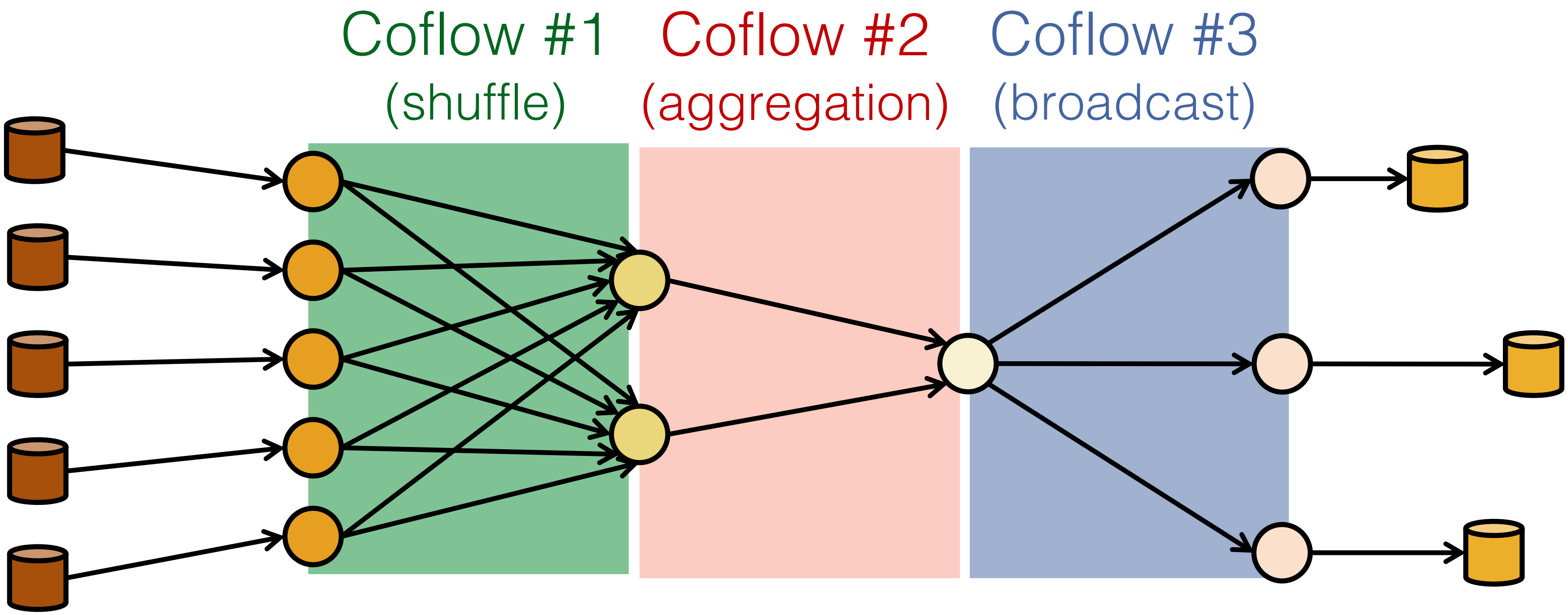
Circuit Switching

larger data?

Fundamental question: Can circuit-switching be **as good as** packet-switching for **big data** traffic?

Big data often comes in Coflows

- Coflow [1] : A set of parallel flows.
- Produced by distributed applications (e.g. Hadoop & Spark).
- Performance is measured by Coflow Completion Time (CCT), i.e. the last flow's completion time.

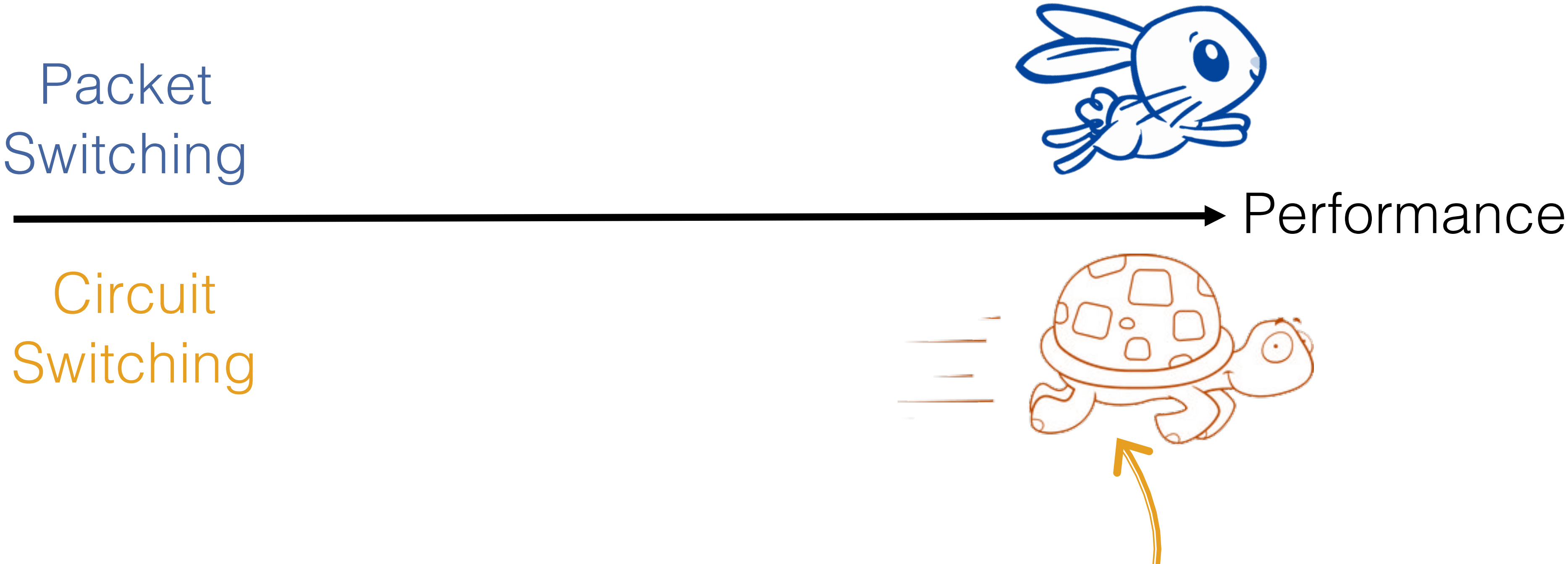


Coflow #1 (shuffle)

Coflow #2 (aggregation)

Coflow #3 (broadcast)

[1] Chowdhury, M. et al. Coflow: An application layer abstraction for cluster networking. (HotNets'12)

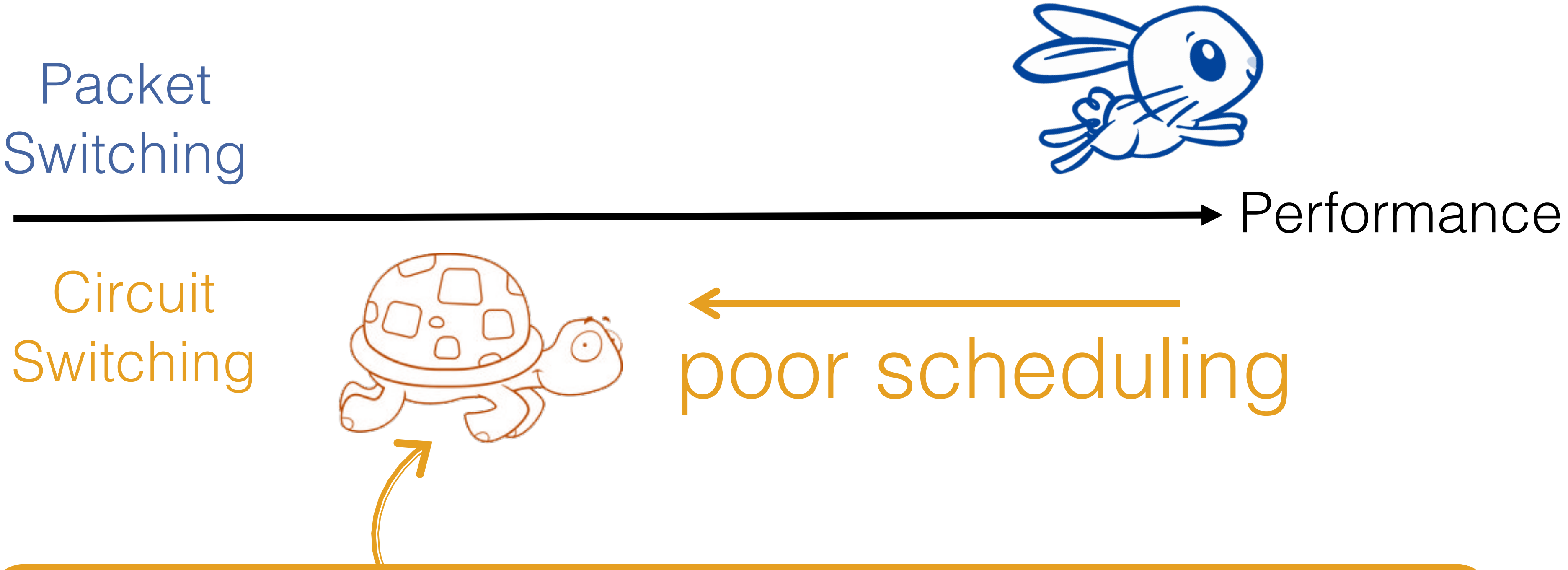


Packet Switching

Performance

Circuit Switching

Fundamental question: Can circuit-switching be as good as packet-switching for **Coflow** traffic?



Packet Switching

Performance

Circuit Switching

poor scheduling

Existing circuit scheduling algorithms: performance suffers from **inefficient** scheduling.

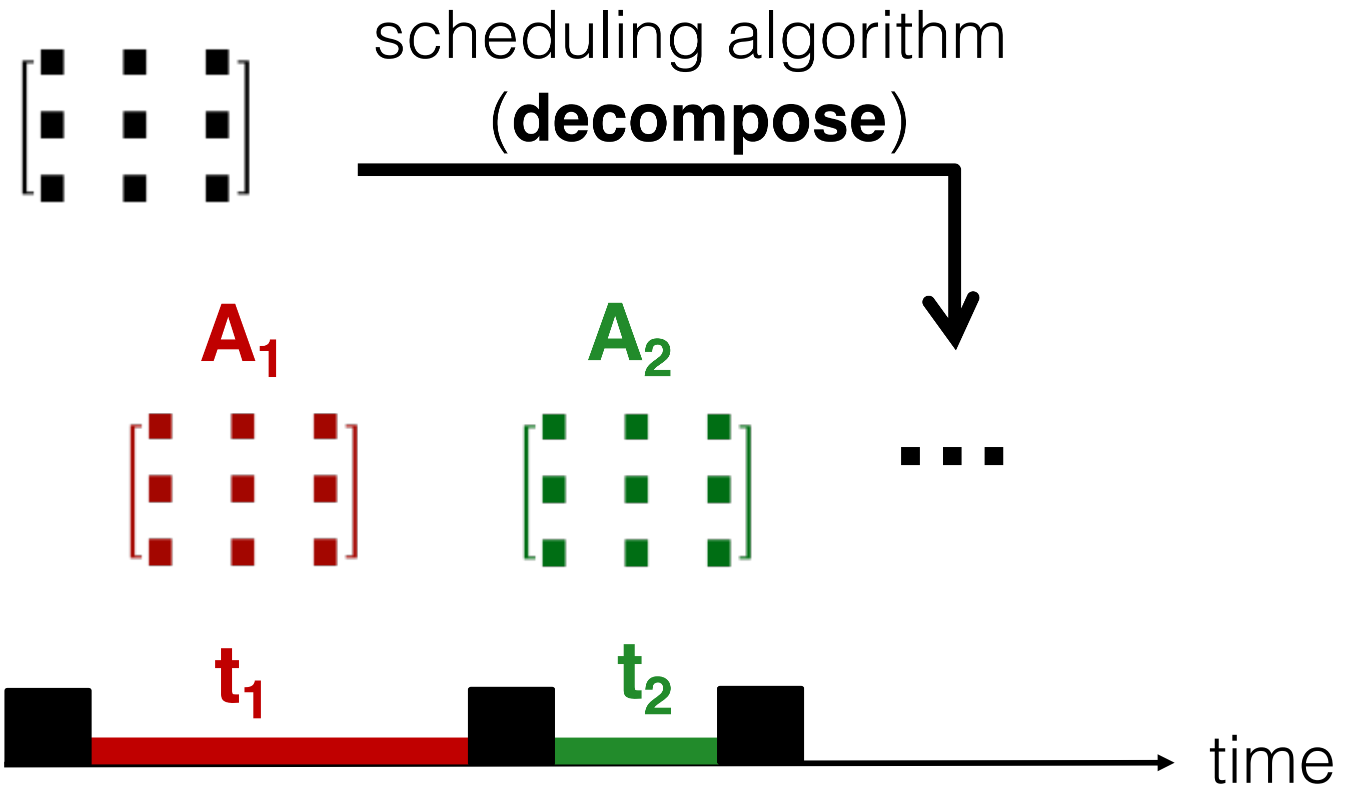
Solstice (CoNEXT'15), **TMS** (SIGCOMM'13), **Max-weighted-matching** in c-through (SIGCOMM'10) and Helios (SIGCOMM'10).

Existing circuit scheduling algorithms all rely on matrix decomposition

Aggregated traffic demand (**matrix**)

A set of circuits (**assignment**)

Active for (**time**)



scheduling algorithm (**decompose**)

A_1

A_2

…

t_1

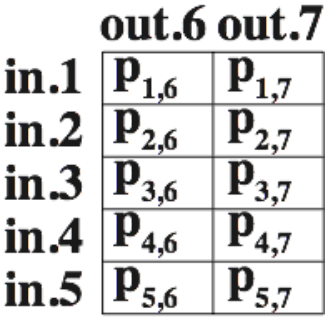
t_2

time

Solstice (CoNEXT'15), **TMS** (SIGCOMM'13), **Max-weighted-matching** in c-through (SIGCOMM'10) and Helios (SIGCOMM'10).

Intra-Coflow circuit scheduling

Coflow
demand matrix



	out.6	out.7
in.1	$p_{1,6}$	$p_{1,7}$
in.2	$p_{2,6}$	$p_{2,7}$
in.3	$p_{3,6}$	$p_{3,7}$
in.4	$p_{4,6}$	$p_{4,7}$
in.5	$p_{5,6}$	$p_{5,7}$

scheduling algorithm
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Intra-Coflow circuit scheduling

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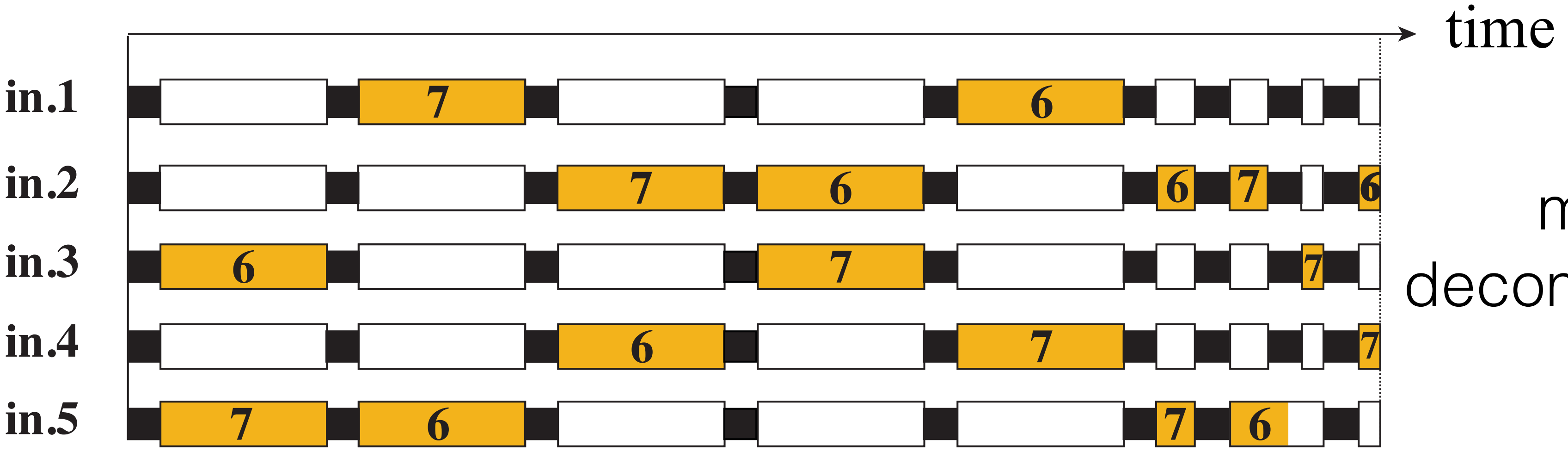
scheduling algorithm (**decompose**)



matrix decomposition*

← duration →

■ **reconfiguration** **output port No.** **circuit scheduled** □ **idle** 🟨 🟦 **transmitting**

* This example is produced by the most efficient algorithm among the existing ones, Solstice (CoNEXT'15).

Intra-Coflow circuit scheduling

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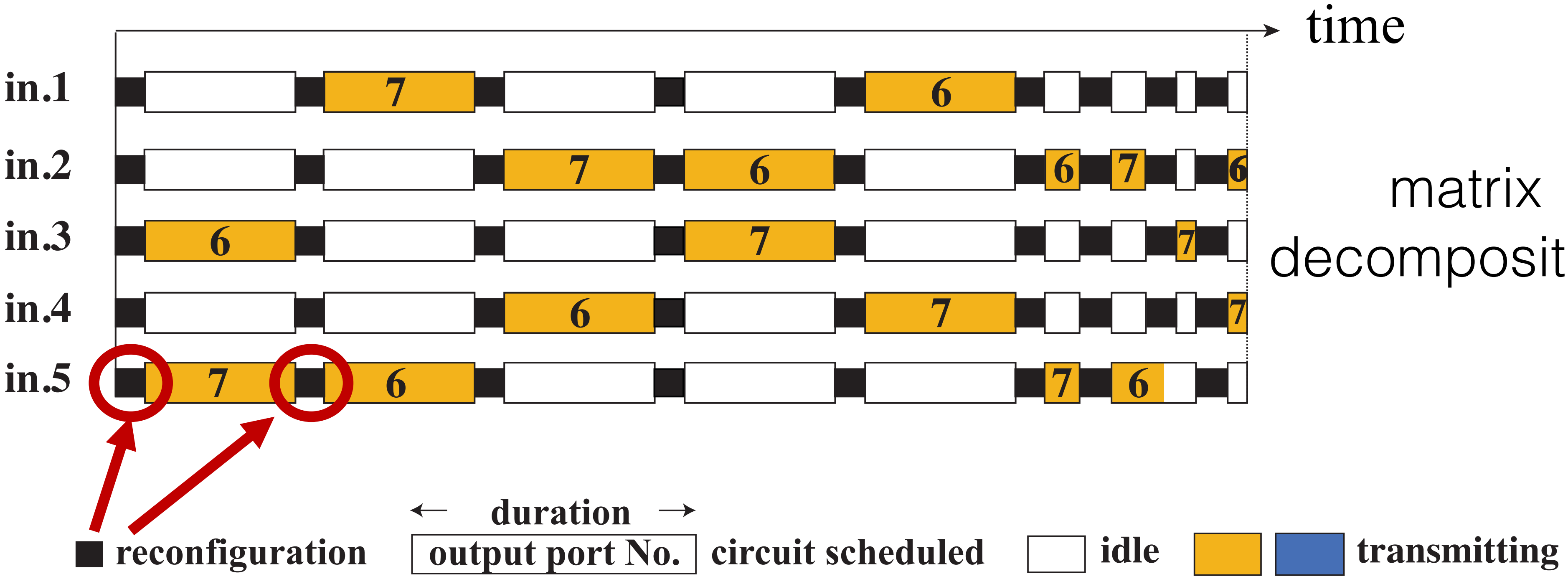

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Intra-Coflow circuit scheduling

Coflow demand matrix

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\text{in.1} & p_{1,6} & p_{1,7} \\
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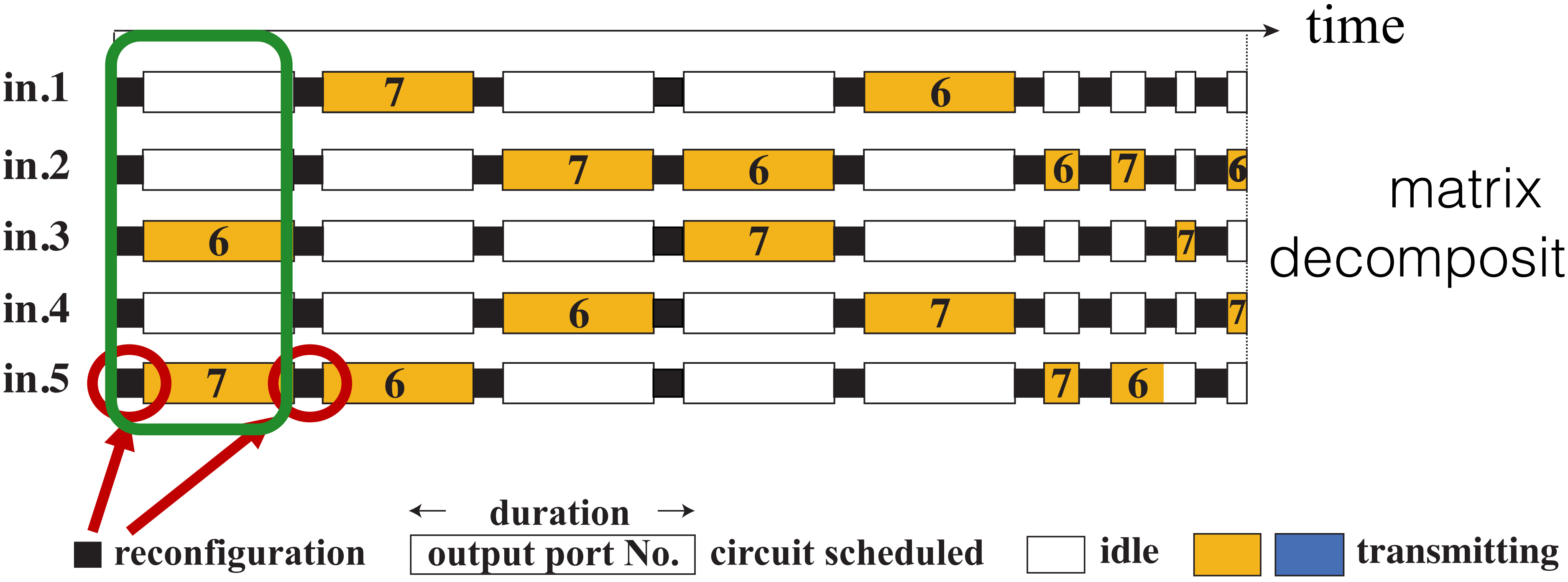
\hline
\text{in.5} & p_{5,6} & p_{5,7} \\
\hline
\end{array}$$

scheduling algorithm (**decompose**)



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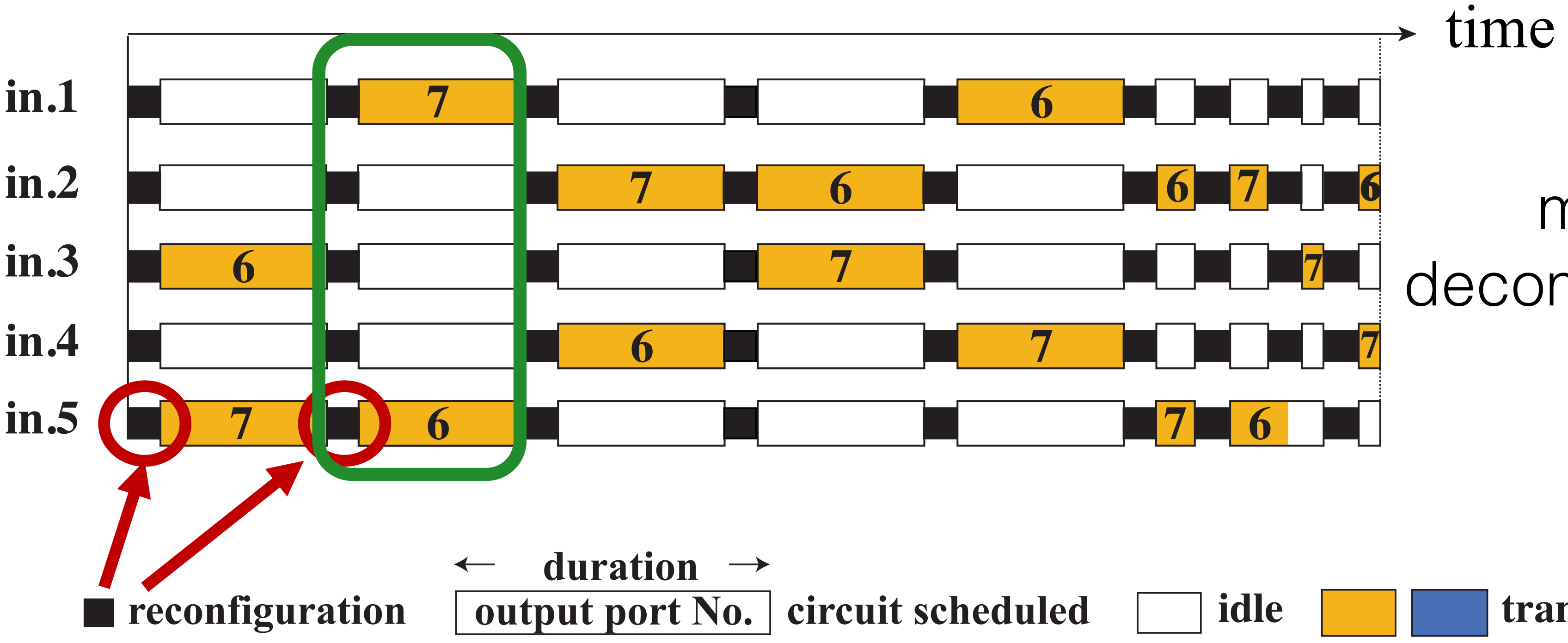

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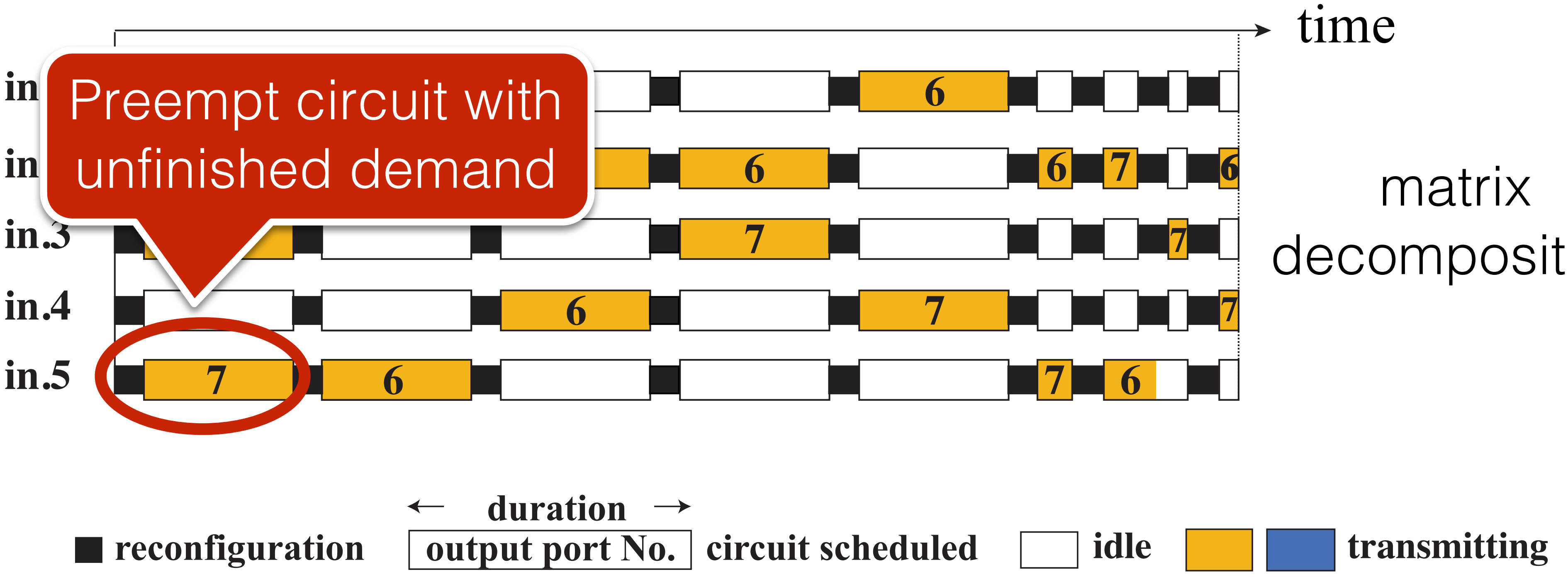

Preempt circuit with unfinished demand

matrix decomposition

Intra-Coflow circuit scheduling

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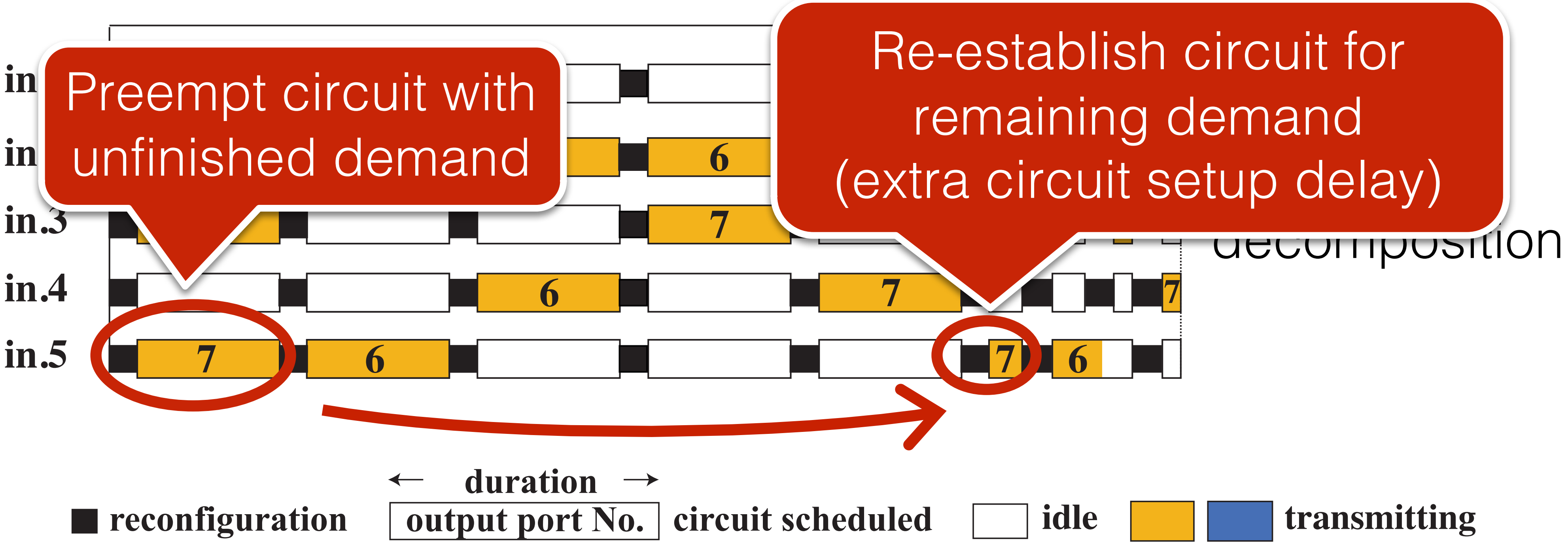
scheduling algorithm (**decompose**)



Preempt circuit with unfinished demand

Re-establish circuit for remaining demand (extra circuit setup delay)

Intra-Coflow circuit scheduling

Overly strong assumption:
All-stop switch model

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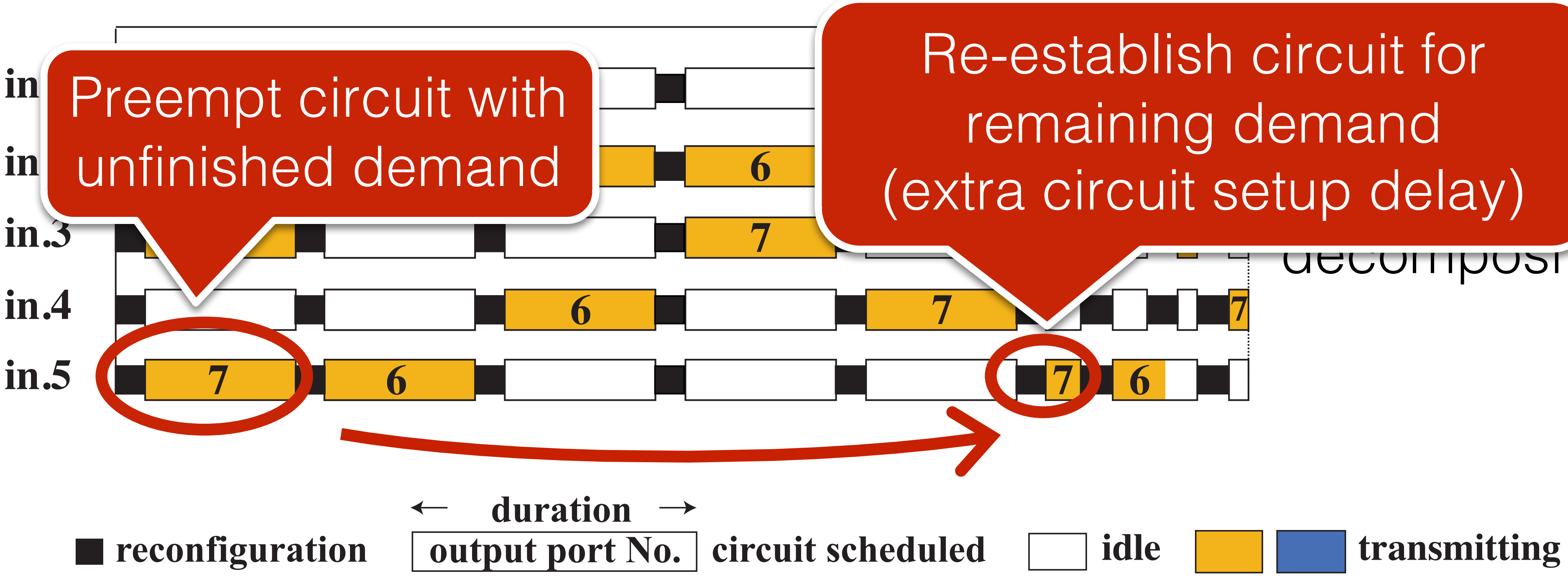

Preempt circuit with unfinished demand

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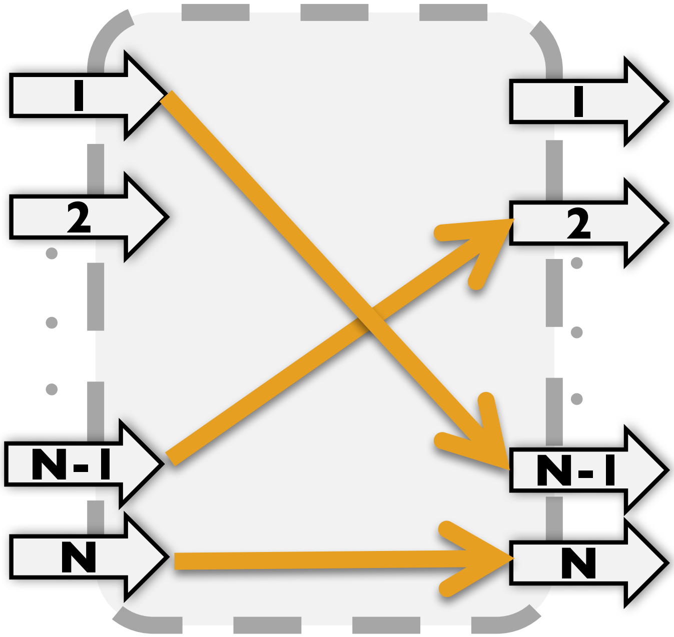
decomposition

All-stop Model

Too strong: All circuits stop during switching.



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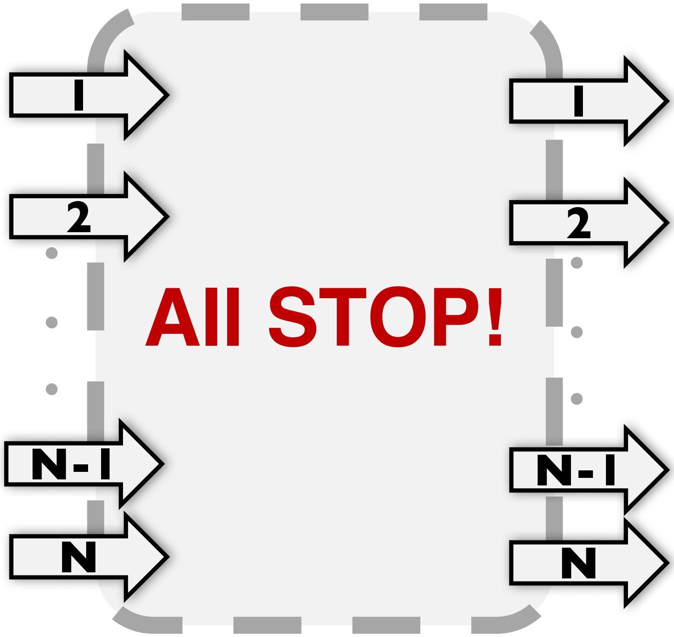

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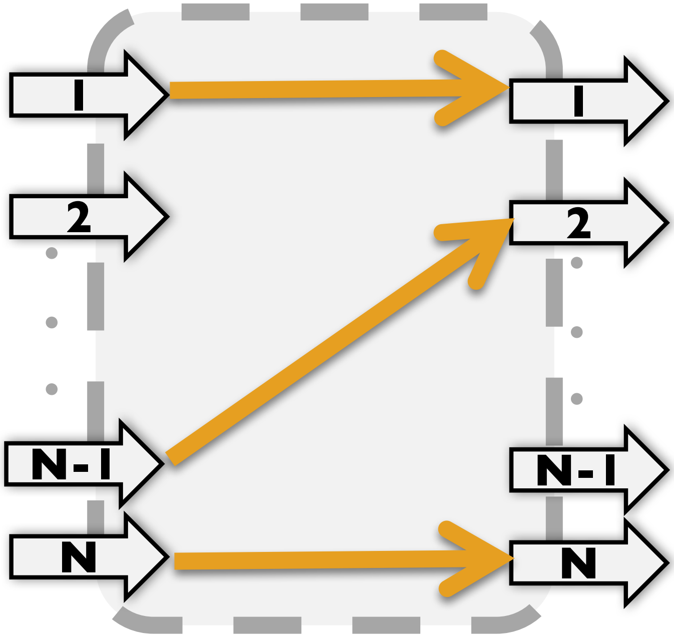

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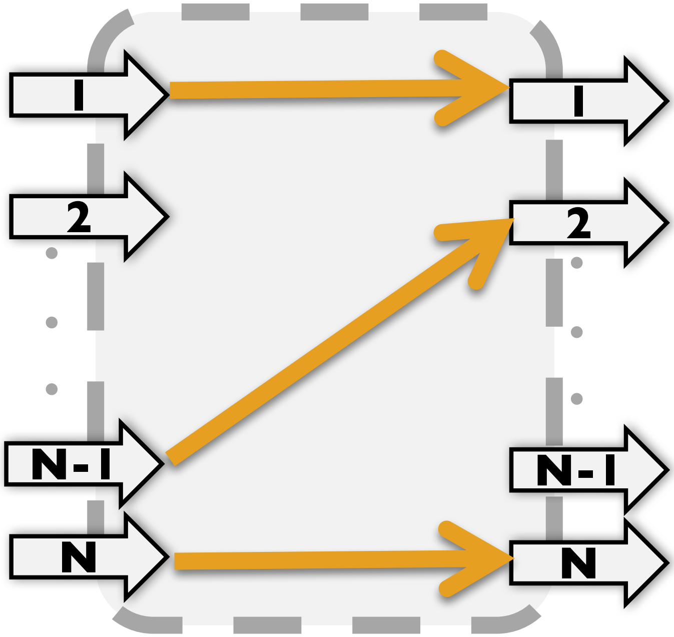

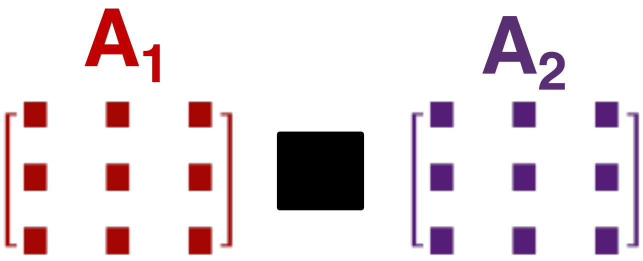

$A_1 \neq A_2$: **NO** incentive to extend any circuit from A_1 to A_2

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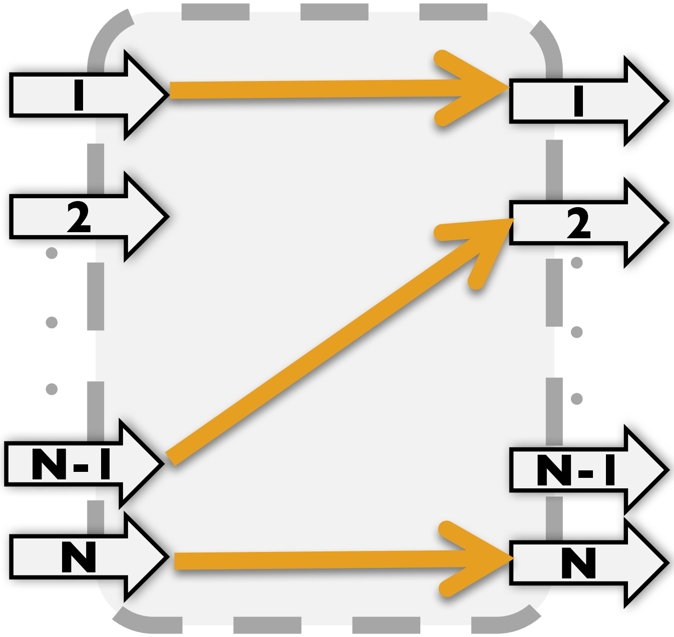
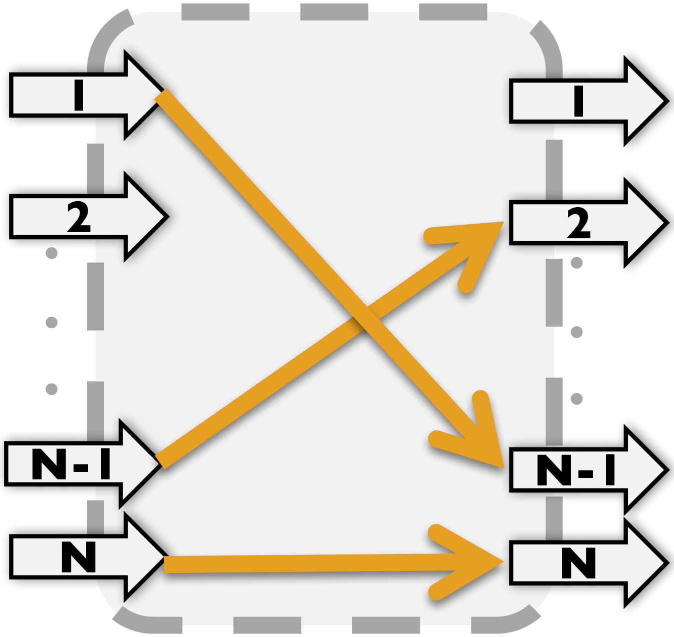


Not-all-stop Model

In practice: Unchanged circuits remain active.



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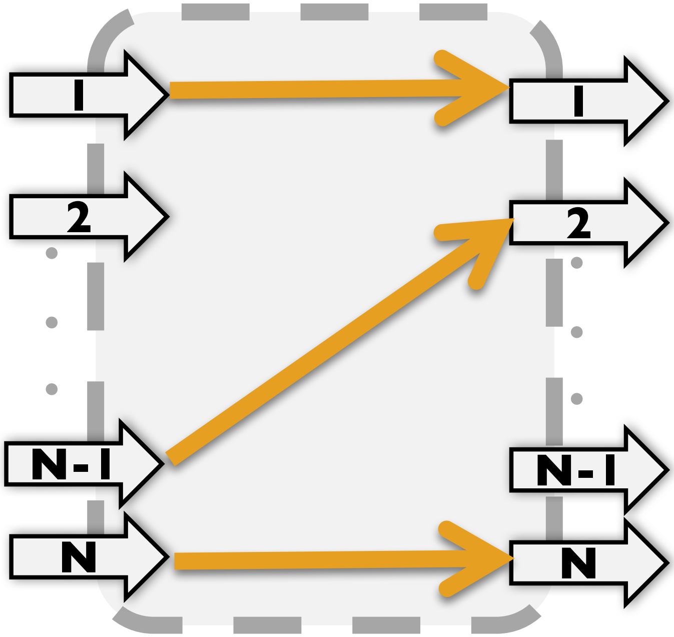

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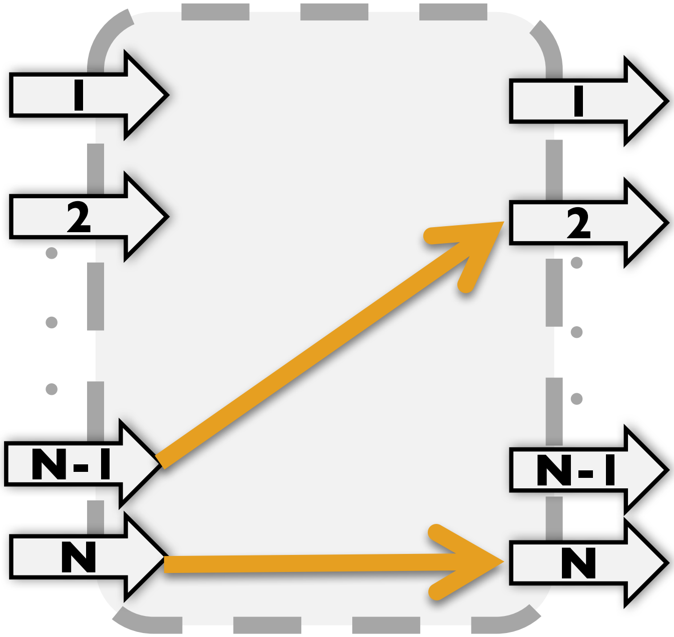

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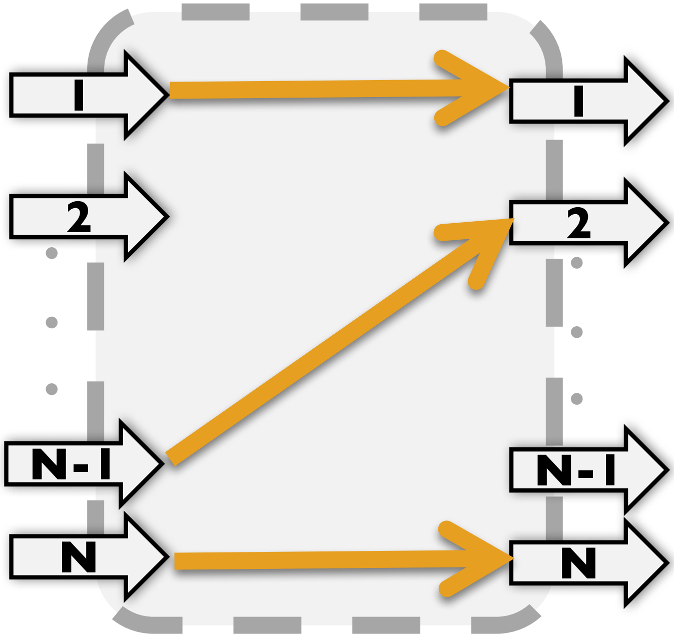

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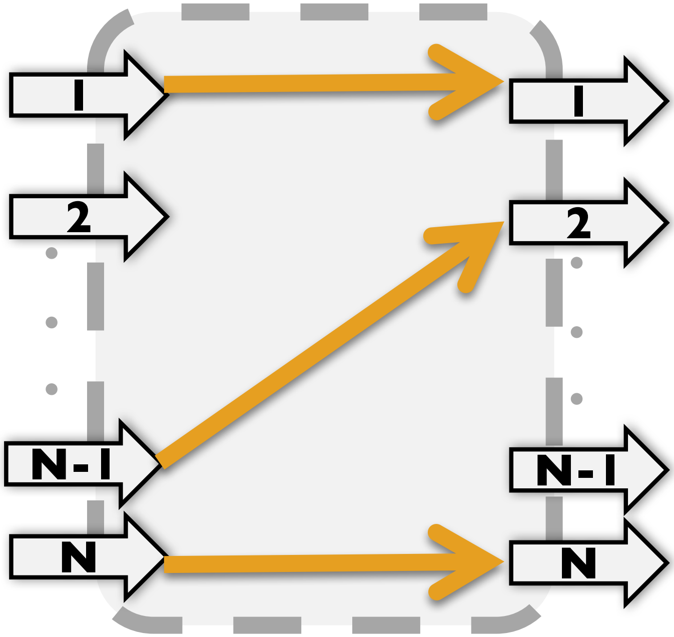

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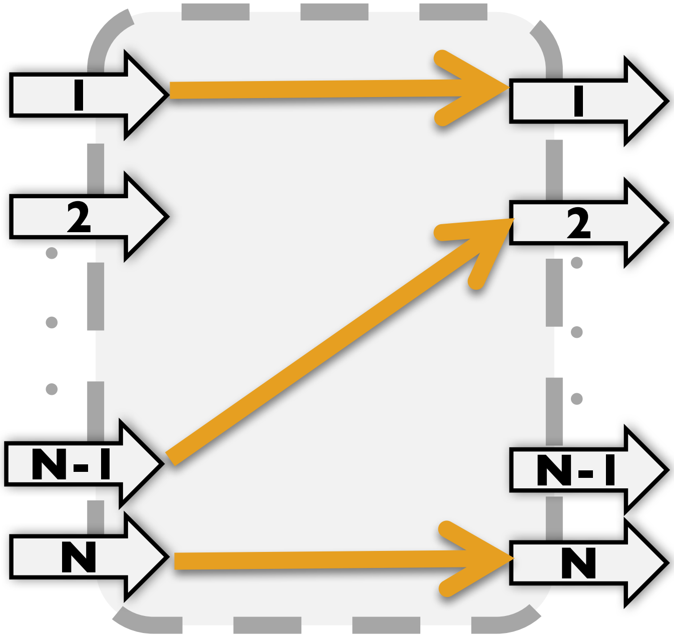

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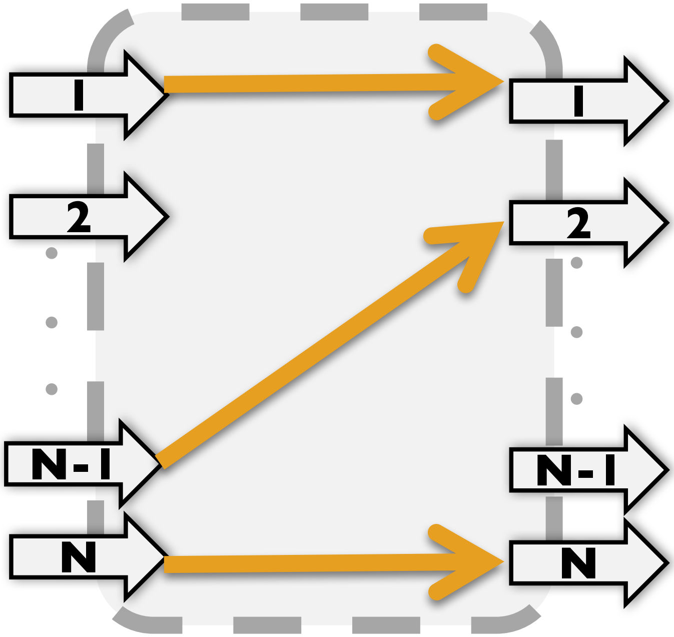
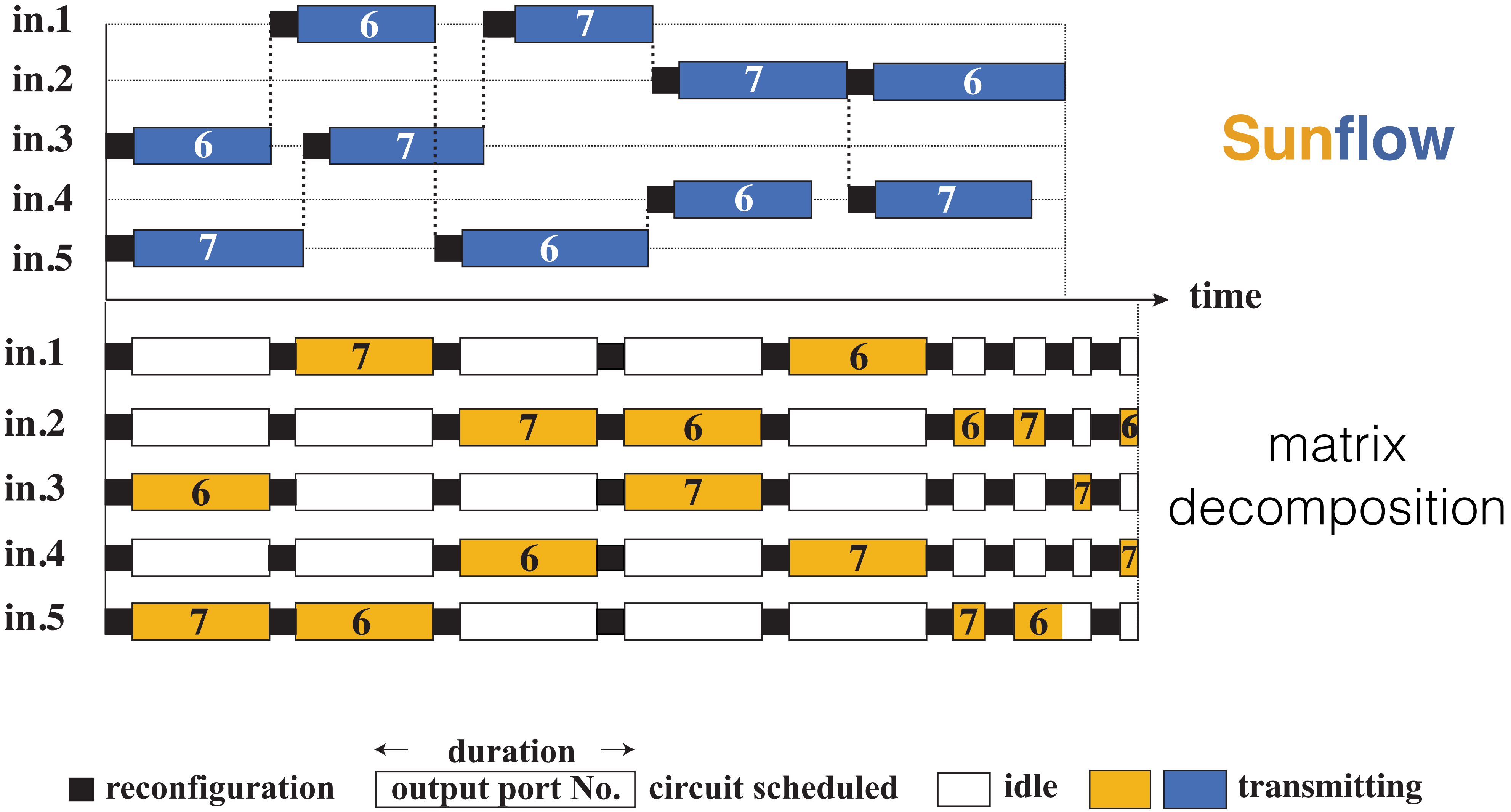


Not-all-stop switch model:
Less stringent and more accurate.

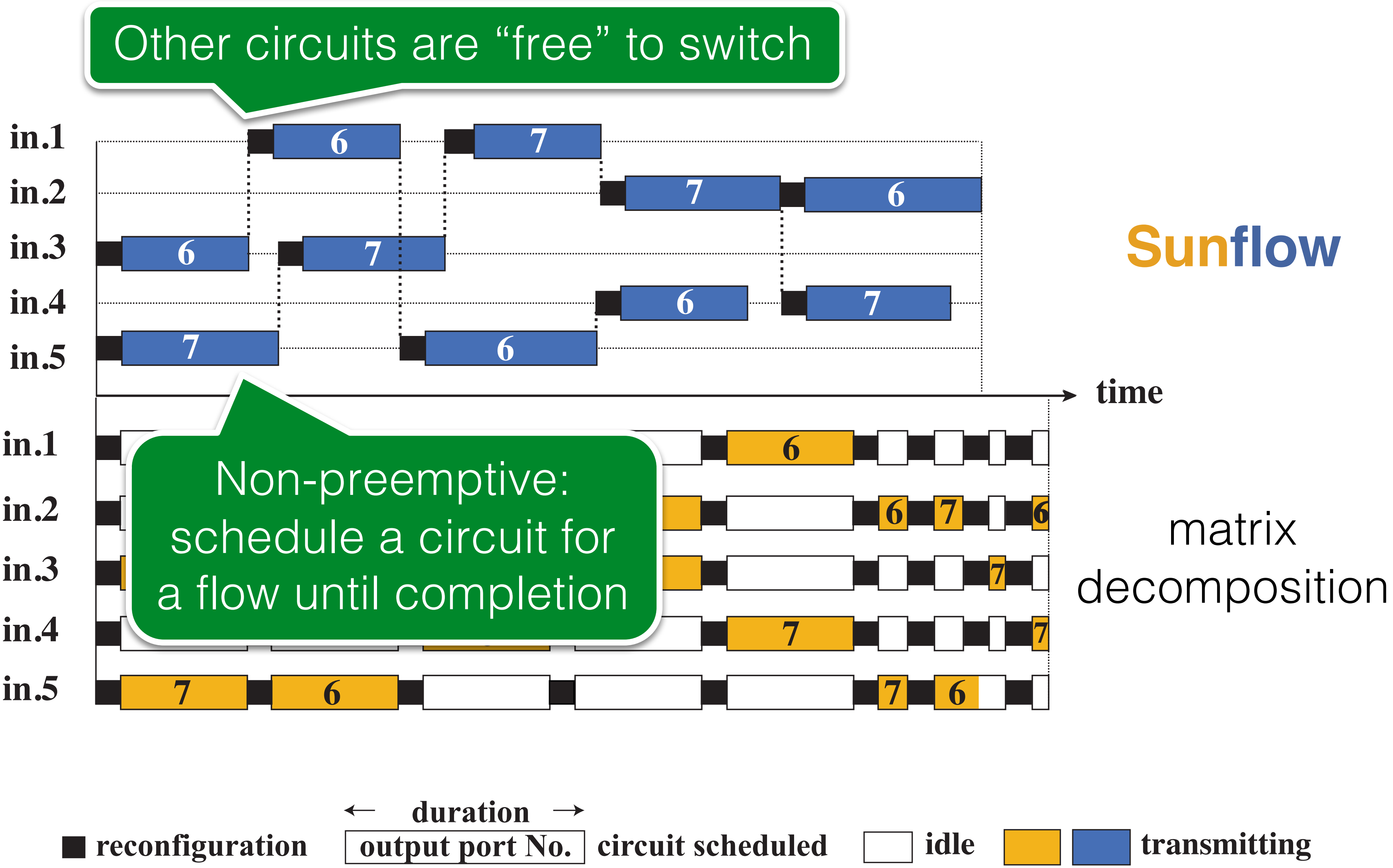
Intra-Coflow circuit scheduling



Sunflow

matrix decomposition

Intra-Coflow circuit scheduling



Other circuits are “free” to switch

Non-preemptive: schedule a circuit for a flow until completion

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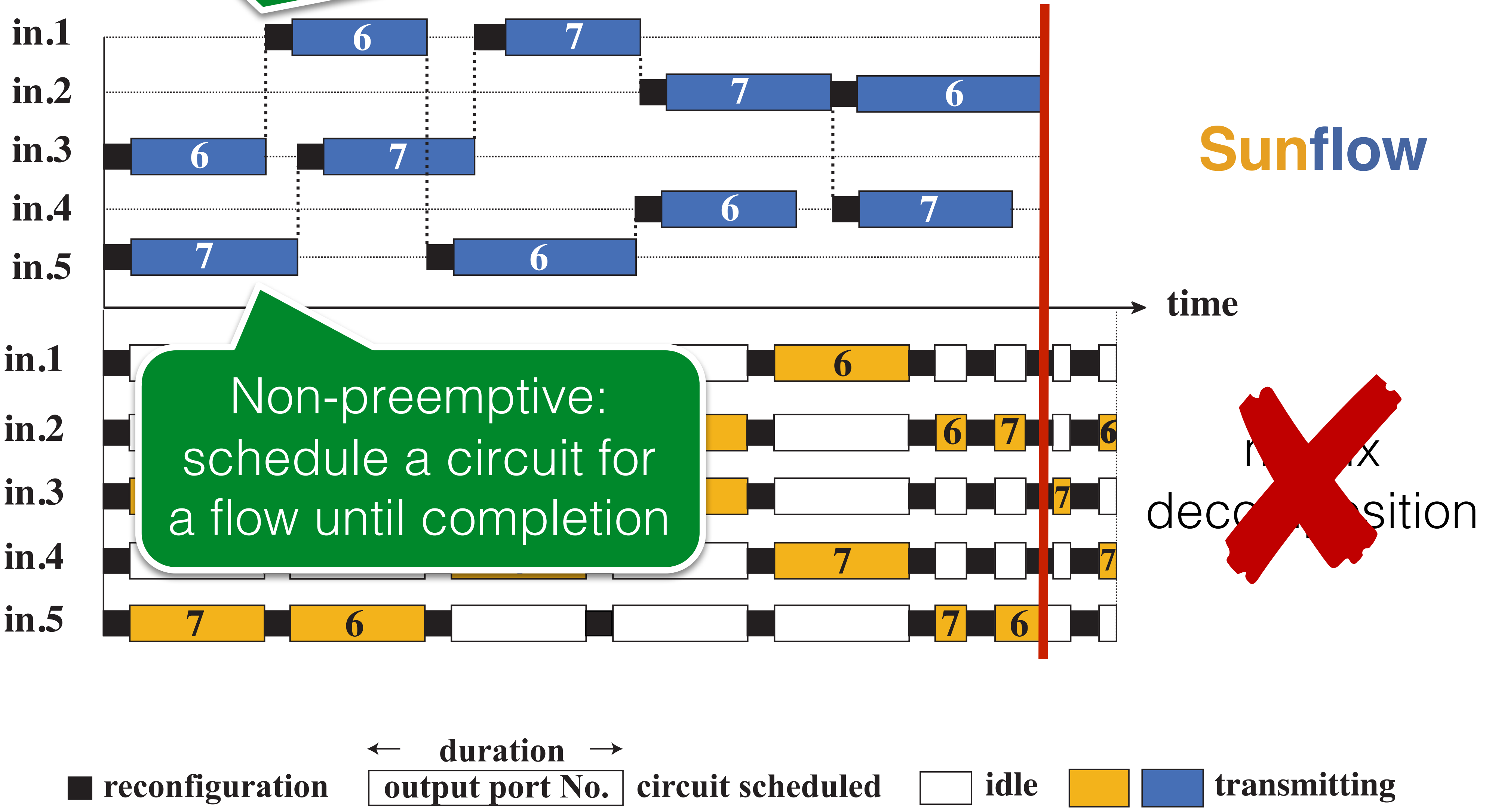

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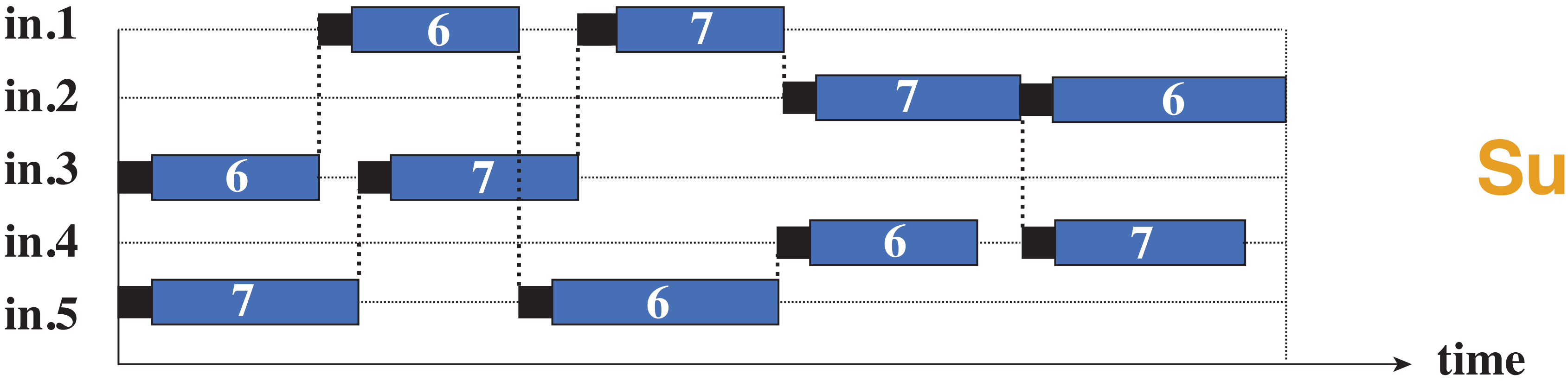


Sunflow

Simple & Efficient!

Greedy heuristic

Provably within 2x optimal,
1.03x in practice …

	Sunflow	Other circuit schedulers
Intra-Coflow	✓ Not allow subflows to preempt each other. ✓ Proved within 2x of the optimal.	✗ Lots of preemptions and switching delay. ✗ Observed 10x optimal.
Inter-Coflow	✓ Flexible preemption policy. (e.g. shortest-Coflow-first)	✗ Aggregated demand matrix loses Coflow boundary.
Switch model	✓ **Not-all-stop (flexible)**	✗ **All-stop (too strong)**

Simulation setup

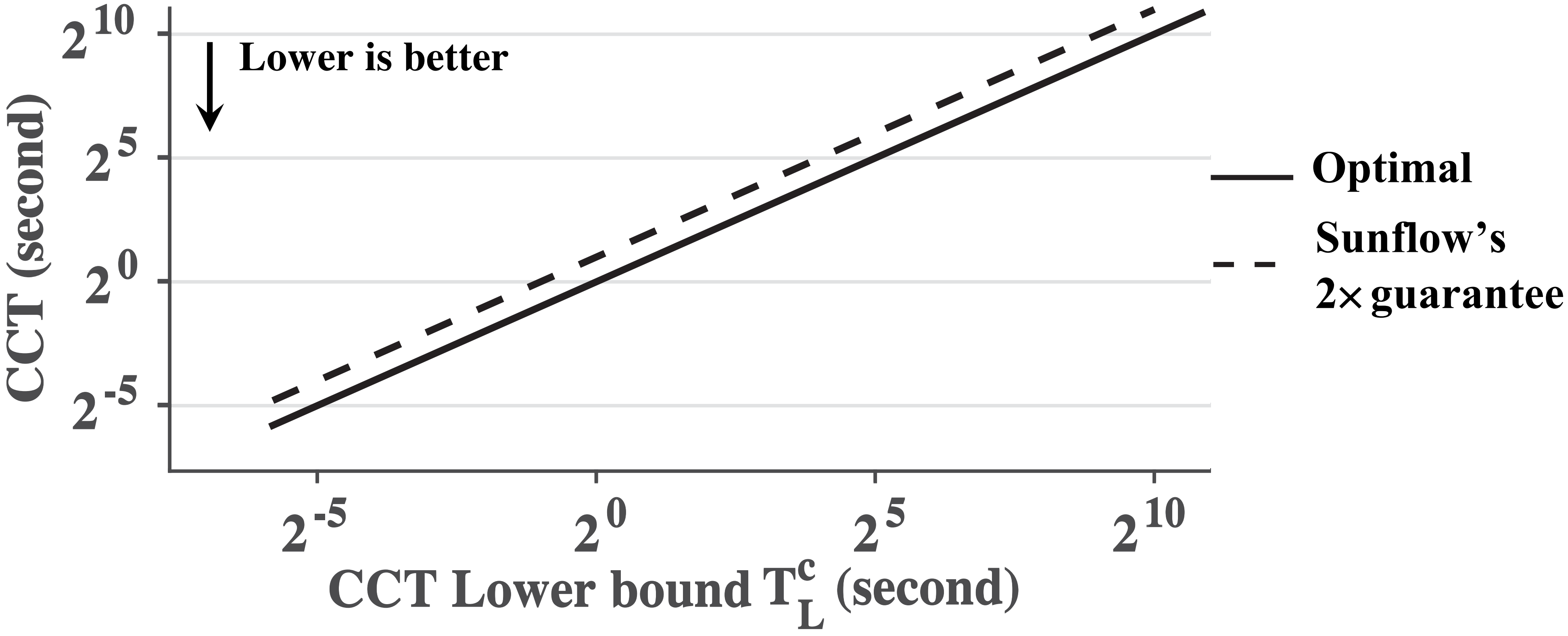
- Implemented a flow-level, discrete-event simulator
- Workload[1] : realistic trace derived from Facebook cluster
  - 1hr traffic trace, ~500 Coflows, ~700k flows
- Circuit switching delay 10 ms (typical of today's products)
- Evaluated at the intra-Coflow and inter-Coflow level

[1] Chowdhury, M. et al. Efficient coflow scheduling with Varys. (SIGCOMM'14)

Simulation results

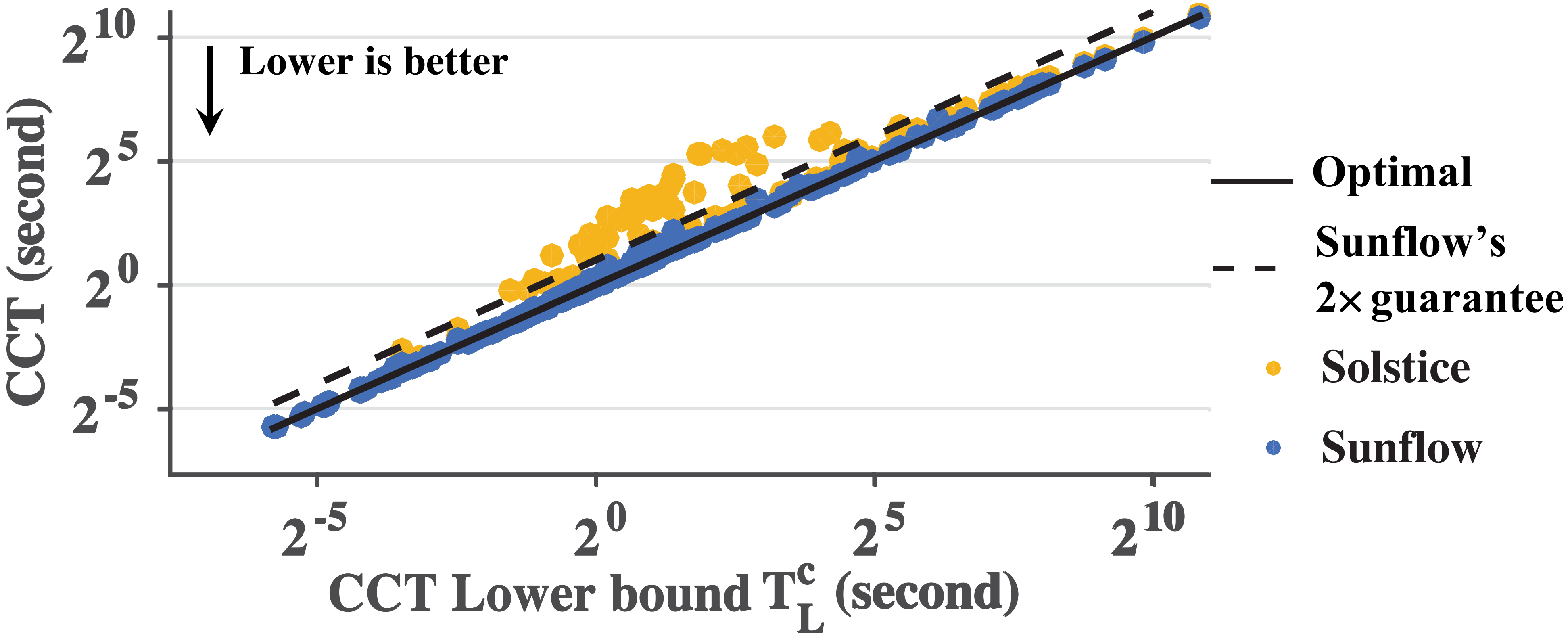
- At the intra-Coflow level:
  - Sunflow is close to **the optimal**
  - Sunflow is more efficient than the most viable circuit scheduling alternative, **Solstice (CoNEXT'15)**

Intra-Coflow circuit scheduling (Sunflow vs Solstice)



Sunflow is more efficient, with performance guarantee

Intra-Coflow circuit scheduling (Sunflow vs Solstice)



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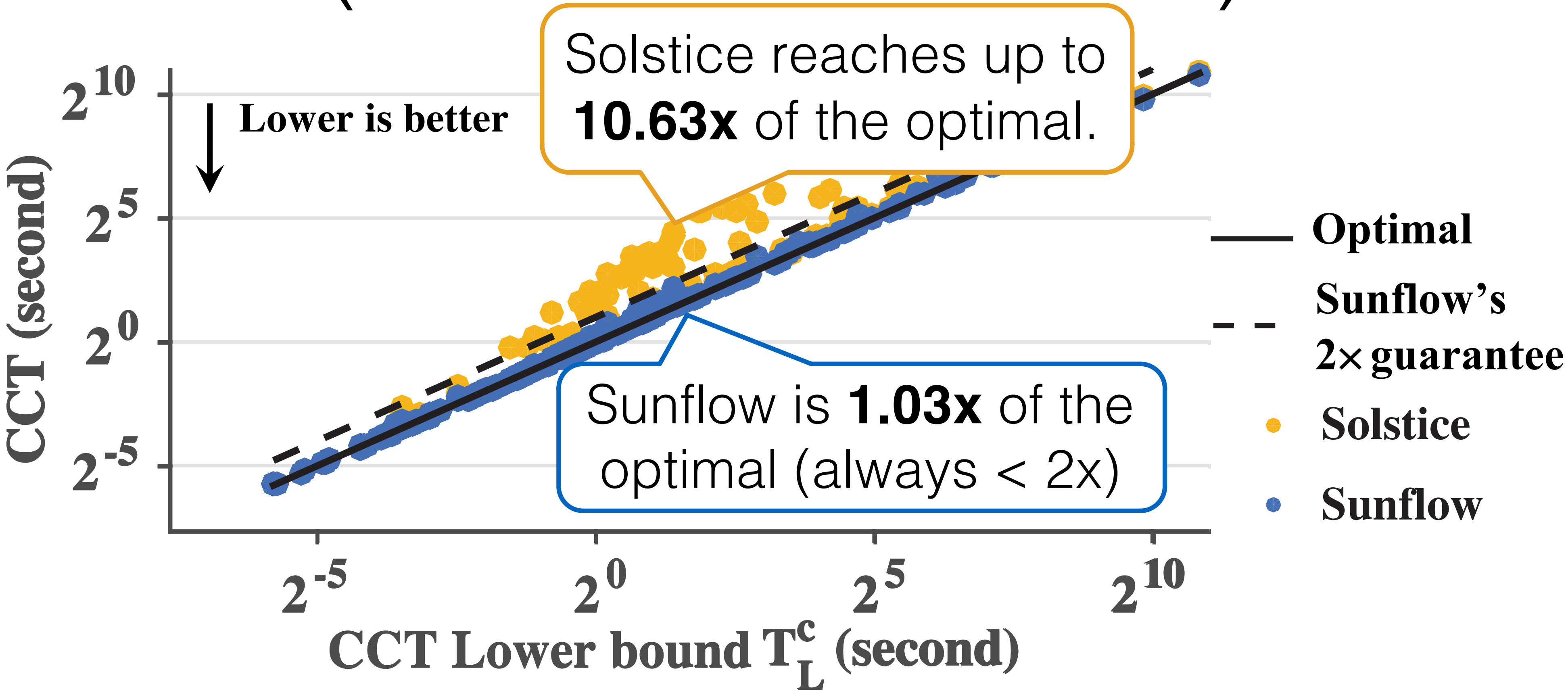
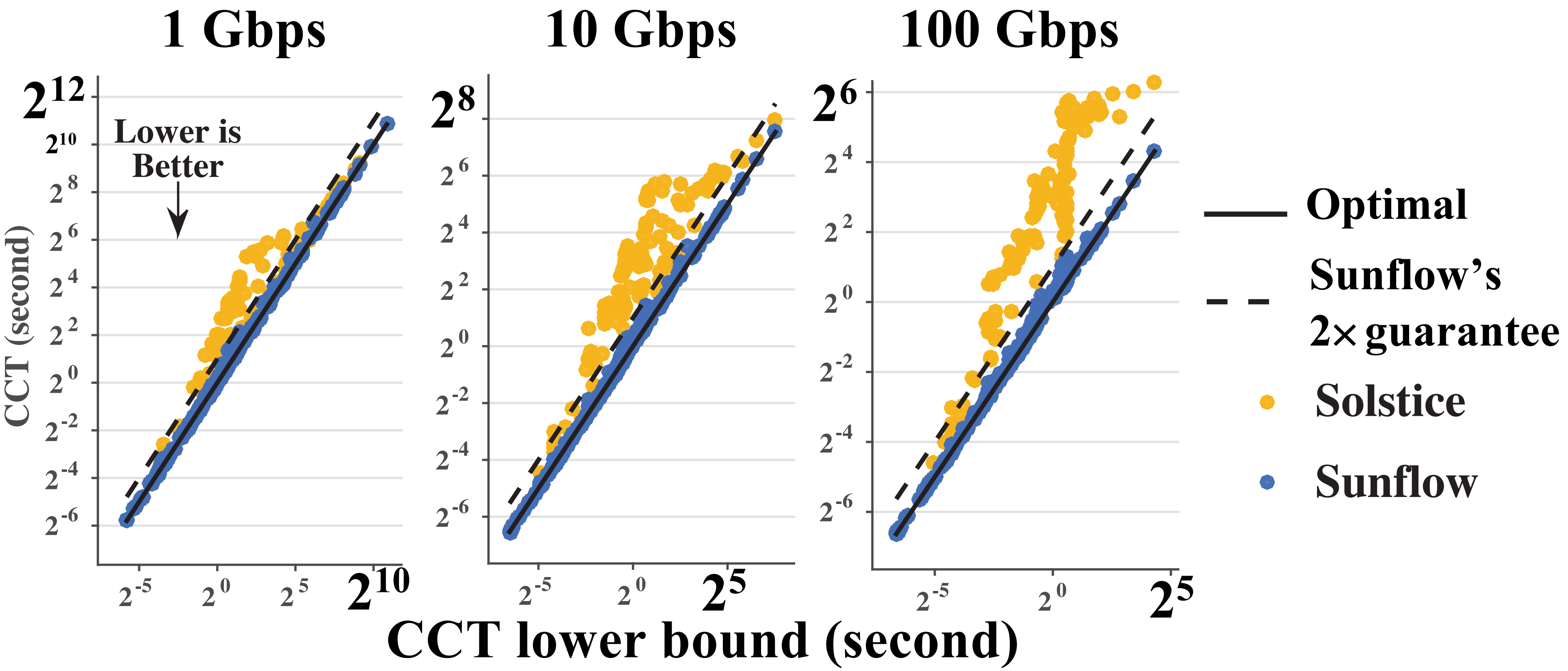


Solstice reaches up to **10.63x** of the optimal.

Sunflow is **1.03x** of the optimal (always < 2x)

Sunflow is more efficient, with performance guarantee

Intra-Coflow circuit scheduling (Sunflow vs Solstice)



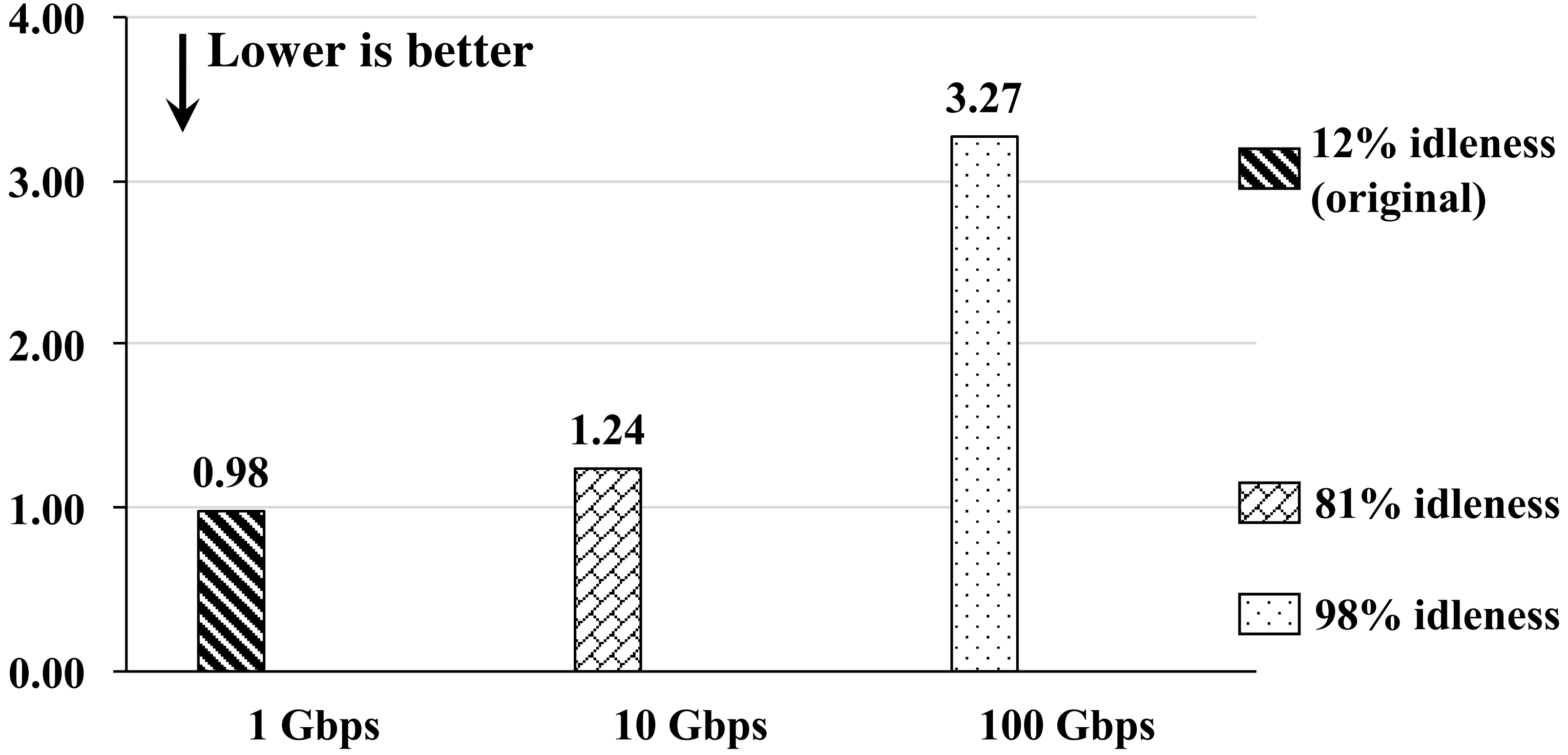
Sunflow is more efficient, with performance guarantee

Simulation results

- At the intra-Coflow level:
    - Sunflow is close to the optimal
    - Sunflow is more efficient than the most viable circuit scheduling alternative, Solstice (CoNEXT'15)
- At the inter-Coflow level:
    - Sunflow's circuit switching achieves performance close to packet-switched Coflow schedulers, Varys (SIGCOMM'14)
    - Same link rate for Sunflow and Varys
    - Sunflow: 10ms switching delay. Varys: no switching delay.

Circuit Switching vs Packet Switching (Sunflow vs Varys)

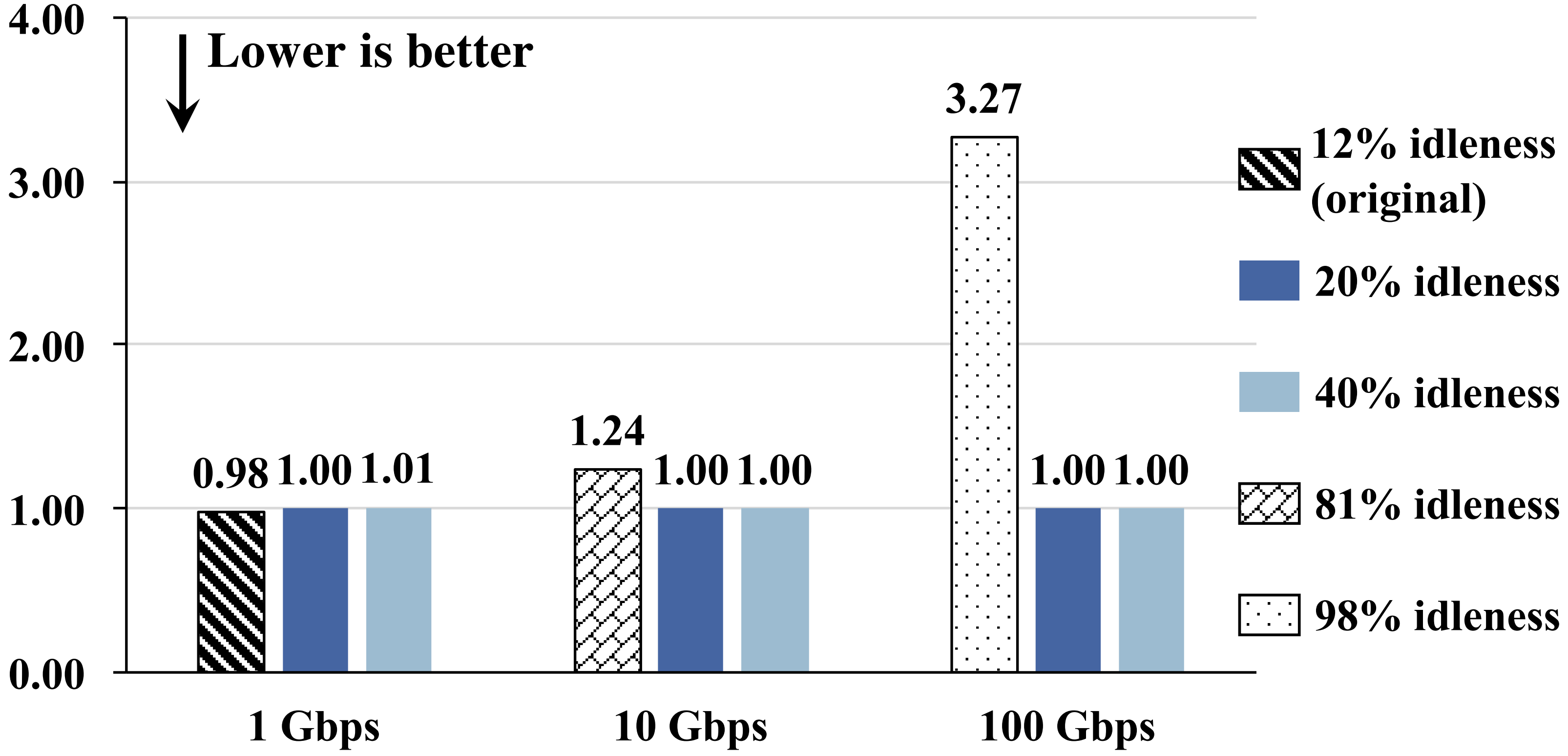
Sunflow's average-CCT over Varys's average-CCT



Change idleness by changing link rate and/or traffic size, but Coflow structures (i.e. flow endpoints) remain the same.

Circuit Switching vs Packet Switching (Sunflow vs Varys)

Sunflow's average-CCT over Varys's average-CCT



Sunflow achieves near-packet-switched performance

Change idleness by changing link rate and/or traffic size, but Coflow structures (flow endpoints) remain the same.

More in the paper

- At the intra-Coflow level:
    - Sunflow's optimality based on Coflow **structures**
    - Sunflow v.s. packet switching based on Coflow **sizes**.
    - **Switching overhead** for Sunflow and Solstice
    - Sensitivity to **flow ordering.**
- At the inter-Coflow level:
    - Sunflow v.s. **Aalo (SIGCOMM'15)**, another Coflow schedulers based on packet switching.
- Sensitivity to **switching delay** at both levels.
- **Proof** of Sunflow's **performance guarantee** against circuit (packet) switching and Sunflow's **complexity**.

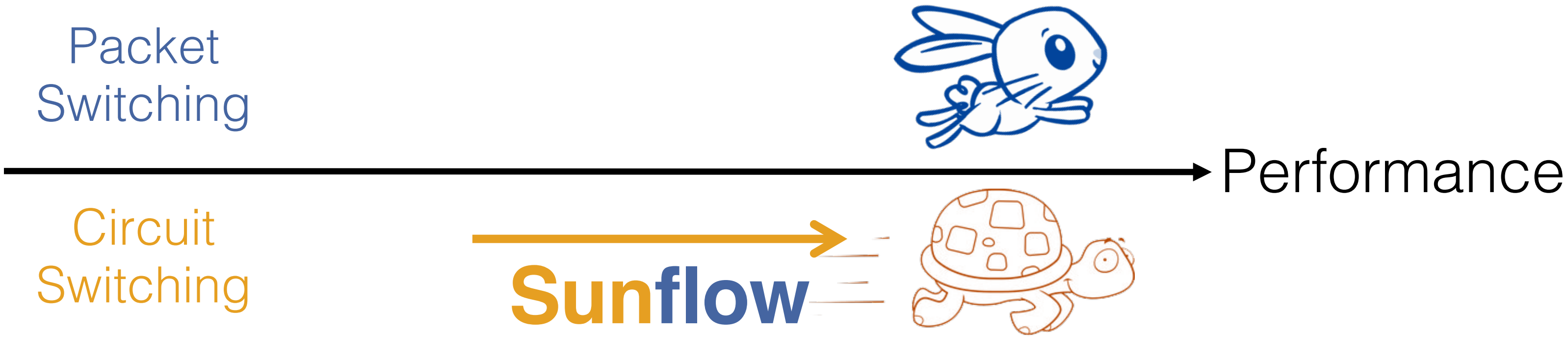
Conclusions

We **can** simultaneously obtain

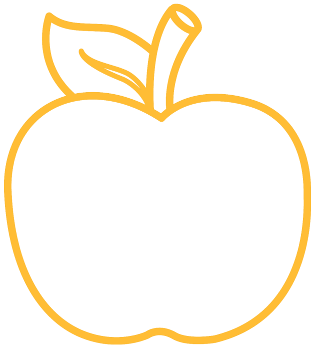
- benefits of optical circuit switching and
- good traffic performance for Coflows!

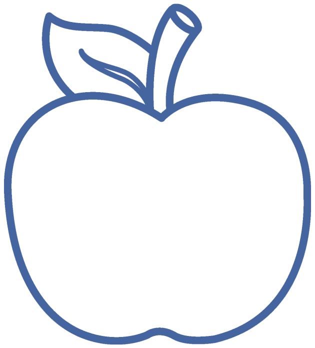
Enabled by **Sunflow**:

- Efficient & flexible *not-all-stop* switch model
- Provably within 2x of the optimal, 1.03x in practice
- Near-packet-switching performance



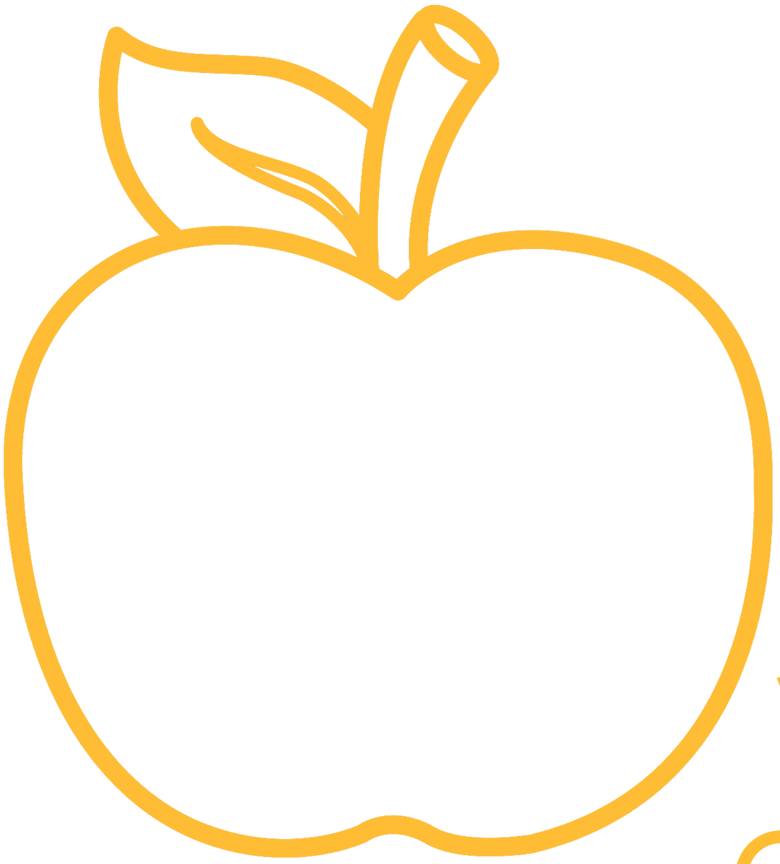
Circuit Switching v.s. Packet Switching

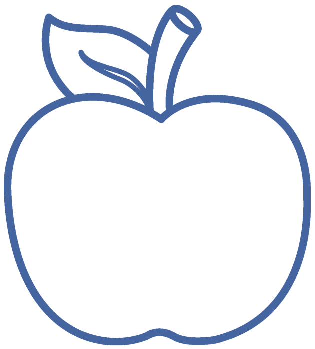




This work is an apple-to-apple comparison between circuit switching and packet switching.

Circuit Switching v.s. Packet Switching





Better potential for
Large capacity

Conclusions

We **can** simultaneously obtain

- benefits of optical circuit switching and
- good traffic performance for Coflows!

Enabled by **Sunflow**:

- Efficient & flexible *not-all-stop* switch model
- Provably within 2x of the optimal, 1.03x in practice
- Near-packet-switching performance

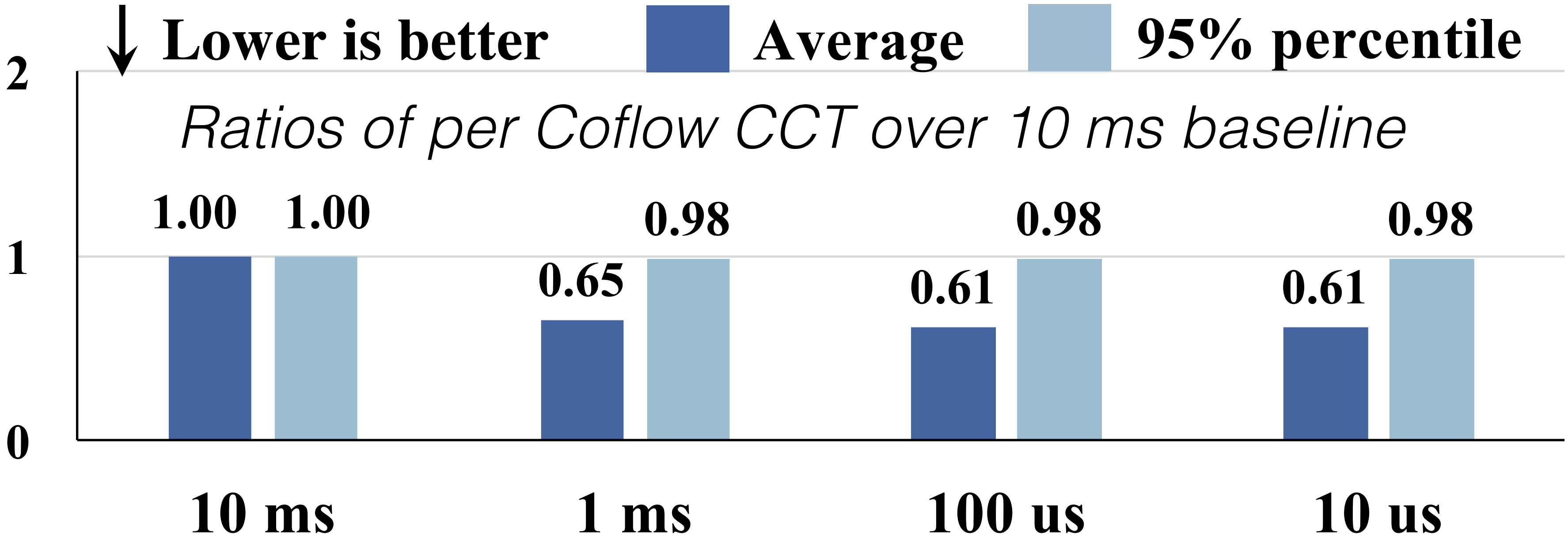
RICE

is recruiting faculty!

Thank You!

Backup slides

Sensitivity to circuit switching delay on *intra*-Coflow scheduling



Product typical

Good to have

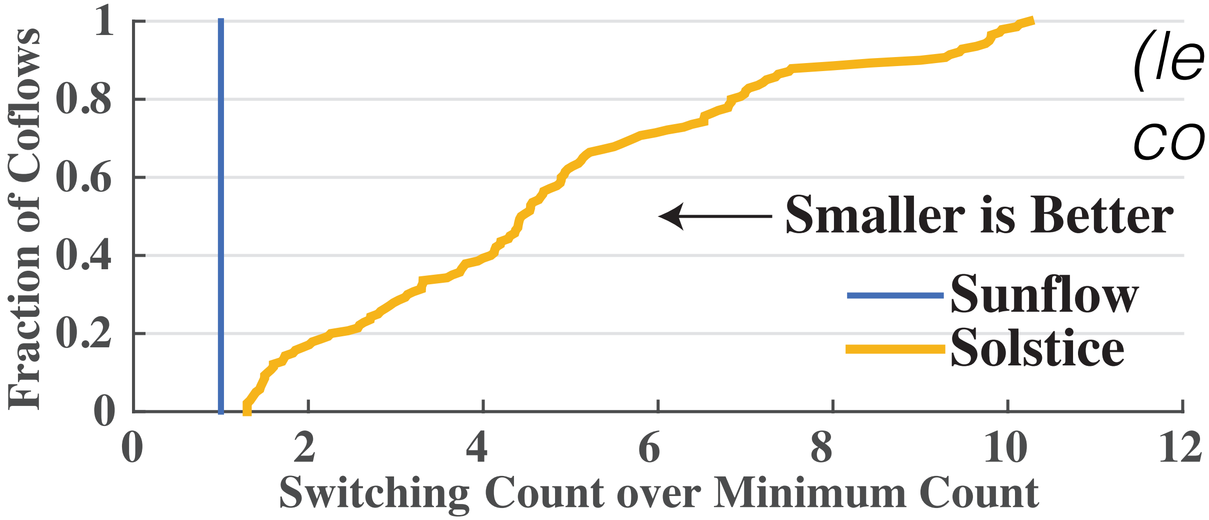
SMALL benefit

millisecond circuit switching is **sufficient** to serve Coflow!

Sunflow v.s. the optimal on ***intra***-Coflow scheduling

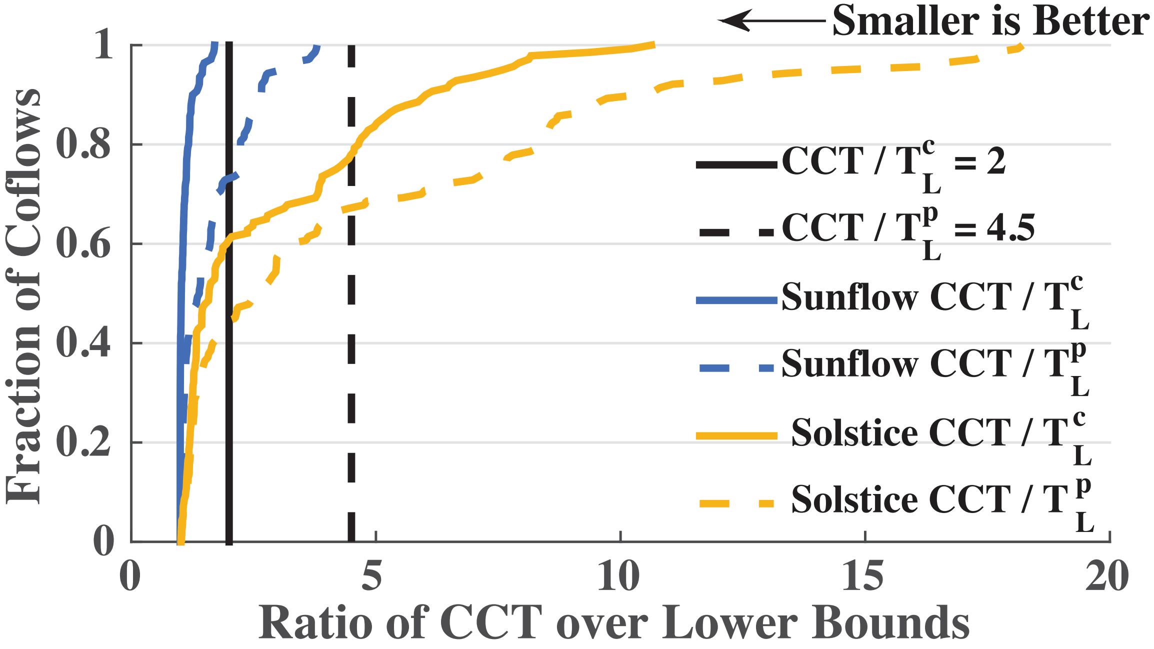
# senders	**> 1**	**> 1**	**1**	**1**	**any**
# receivers	**> 1**	**1**	**> 1**	**1**	**any**
% bytes	99.9%	0.028%	0.024%	0.005%	100%
% Coflows	26.6%	40.1%	9.9%	23.4%	100%
Sunflow CCT	**1.10x optimal**	**optimal**	**optimal**	**optimal**	**1.03x optimal**

Circuit Switching Overhead (Sunflow v.s. Solstice)



(left) Distribution of switching count for M2M Coflows

result in



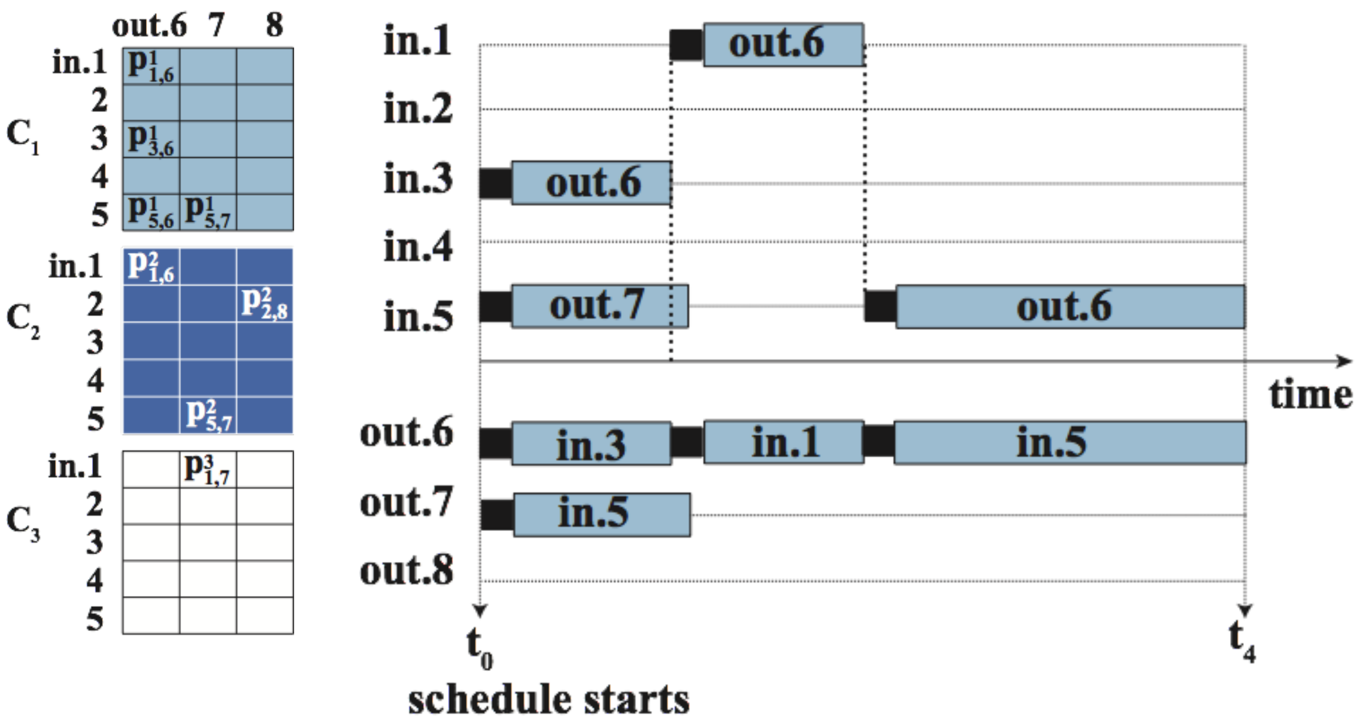
(right) Distribution of $CCT/T^C{}_L$ and $CCT/T^L{}_p$ for M2M Coflows

Sunflow v.s. Varys on ***inter***-Coflow scheduling

average flow size ≥ 5 MB

	Long Coflows	Short Coflows	All
% bytes	**98.8%**	1.2%	100%
% Coflows	25.2%	74.8%	100%
Per Coflow $\frac{\textbf{Sunflow CCT}}{\textbf{Varys CCT}}$	**1.07x**	2.16x	1.87x

Inter-Coflow circuit scheduling

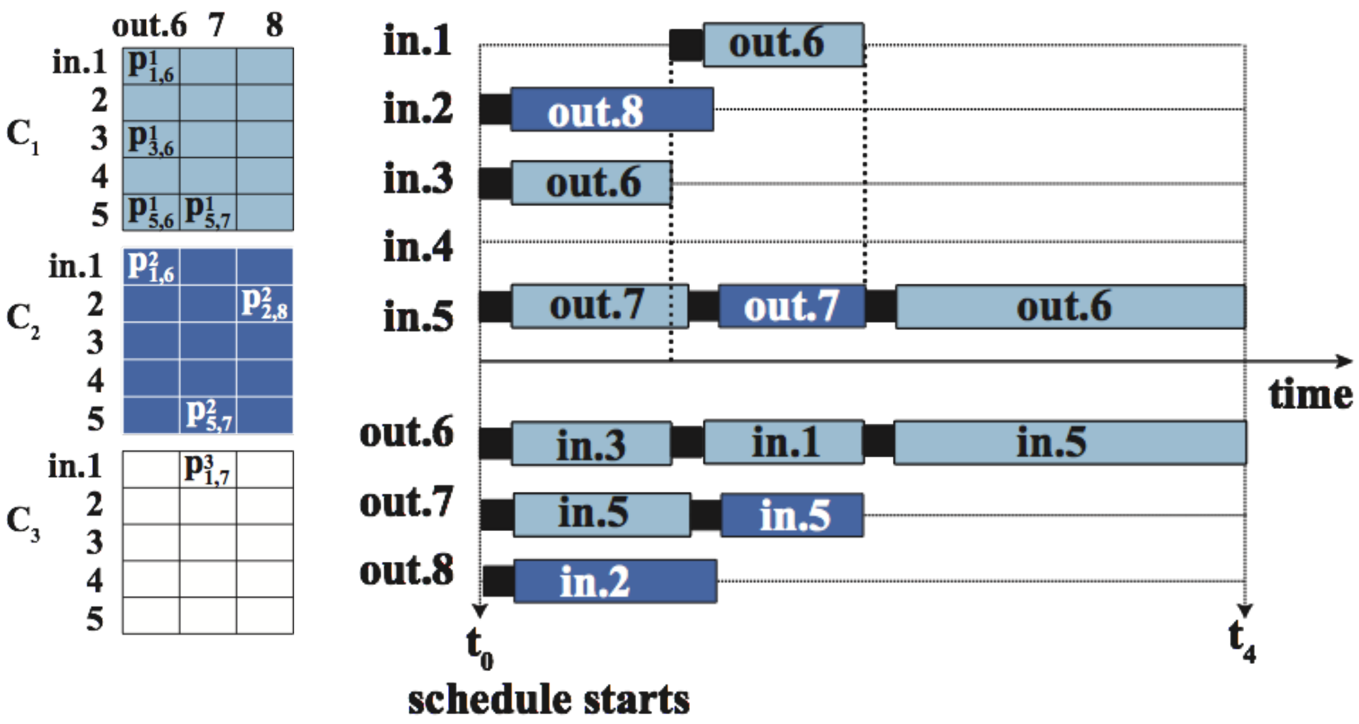


		out.6	7	8
C_1	in.1	$p^1_{1,6}$		
	2			
	3	$p^1_{3,6}$		
	4			
	5	$p^1_{5,6}$	$p^1_{5,7}$	
C_2	in.1	$p^2_{1,6}$		
	2			$p^2_{2,8}$
	3			
	4			
	5		$p^2_{5,7}$	
C_3	in.1		$p^3_{1,7}$	
	2			
	3			
	4			
	5			

Schedule C1

- Sort Coflow on priority.
- Assign *circuit active time* for flows.

Inter-Coflow circuit scheduling

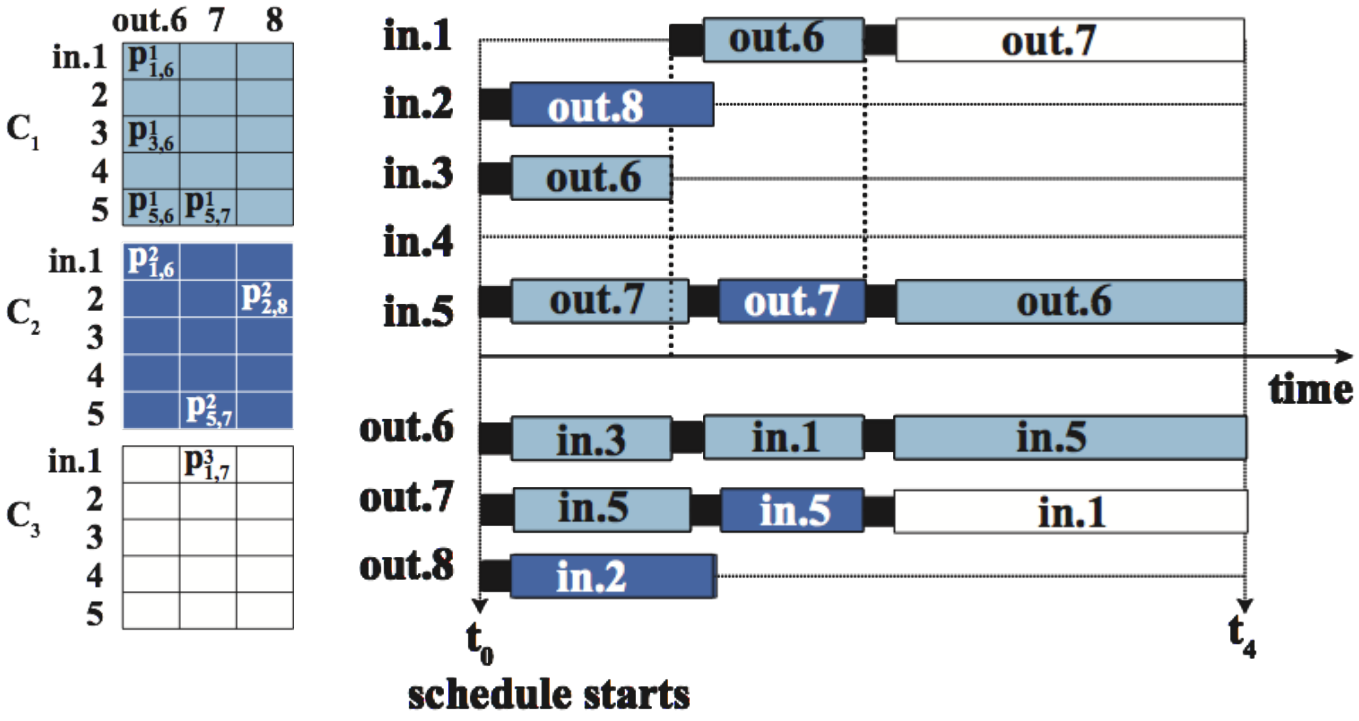


Schedule C1

Schedule C2

- Sort Coflow on priority.
- Assign *circuit active time* for flows.

Inter-Coflow circuit scheduling



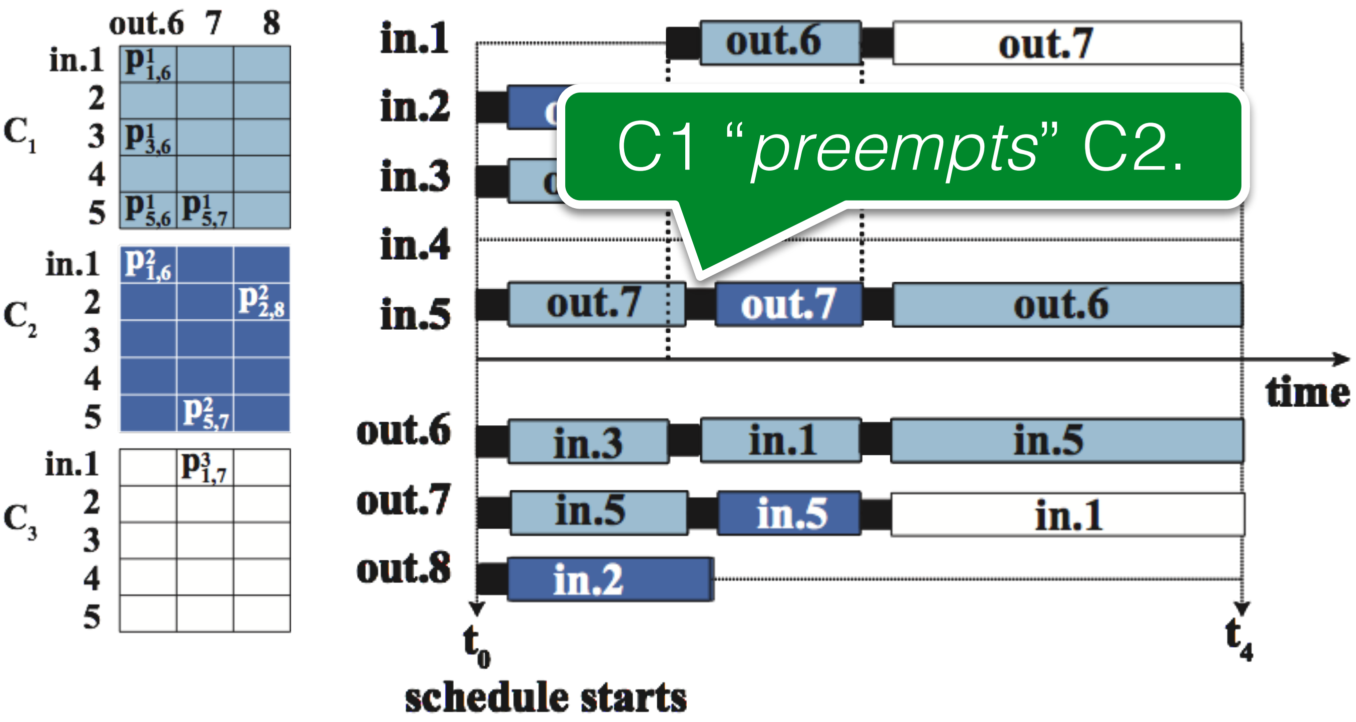
Schedule C1

Schedule C2

Schedule C3

- Sort Coflow on priority.
- Assign *circuit active time* for flows.

Inter-Coflow circuit scheduling



C1 “*preempts*” C2.

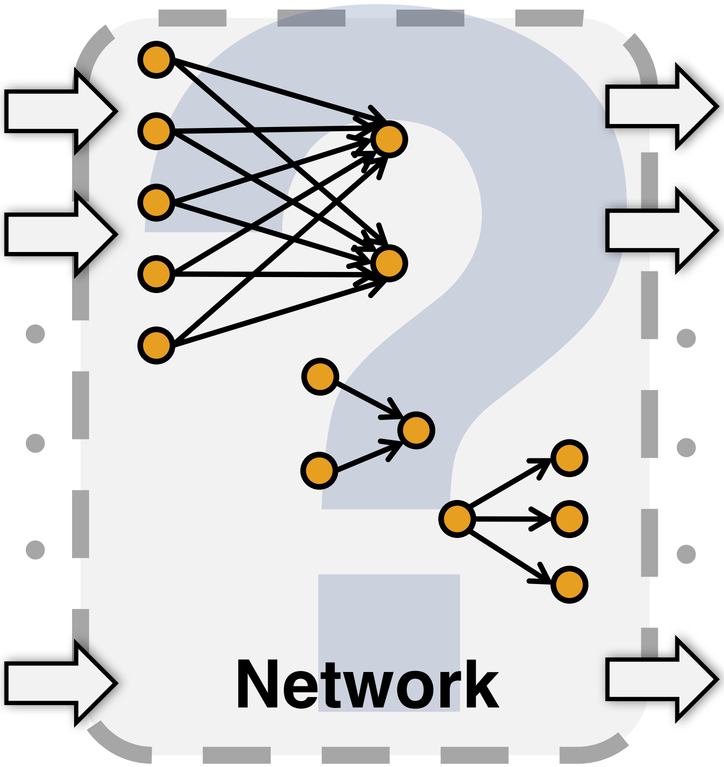
Schedule C1

Schedule C2

Schedule C3

High priority Coflow can preempt circuits from low priority Coflow.

Previous work on Coflow-aware network scheduling



- Why? Optimizing CCT reduces job completion time.[1]
- Key idea: Coordinate and schedule Coflows upon contention.
- Previous works are all in **packet** switching:
  - Min Σ CCTs (*Varys* in SIGCOMM'14)[2] ★
  - Other variants:
    uncertain Coflow byte size ('15)[3],
    uncertain Coflow structures ('16)[4]

[1] Chowdhury, M. et al. Coflow: An application layer abstraction for cluster networking. (HotNets'12)
[2] Chowdhury, M. et al. Efficient coflow scheduling with Varys. (SIGCOMM'14)
[3] Chowdhury, M. et al. Efficient coflow scheduling without prior knowledge. (SIGCOMM'15)
[3] Zhang, H. et al. CODA: Toward Automatically Identifying and Scheduling Coflows in the Dark. (SIGCOMM'16)

Thank You!

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Rice University

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Big Data and Optical Lightpaths Driven Lab