

96-1268: MIMO Latency - Revised Definition

Raj Jain, Gojko Babic
The Ohio State University

Contact: Jain@CIS.Ohio-State.Edu
<http://www.cis.ohio-state.edu/~Jain/>

Overview



Input frame not contiguous

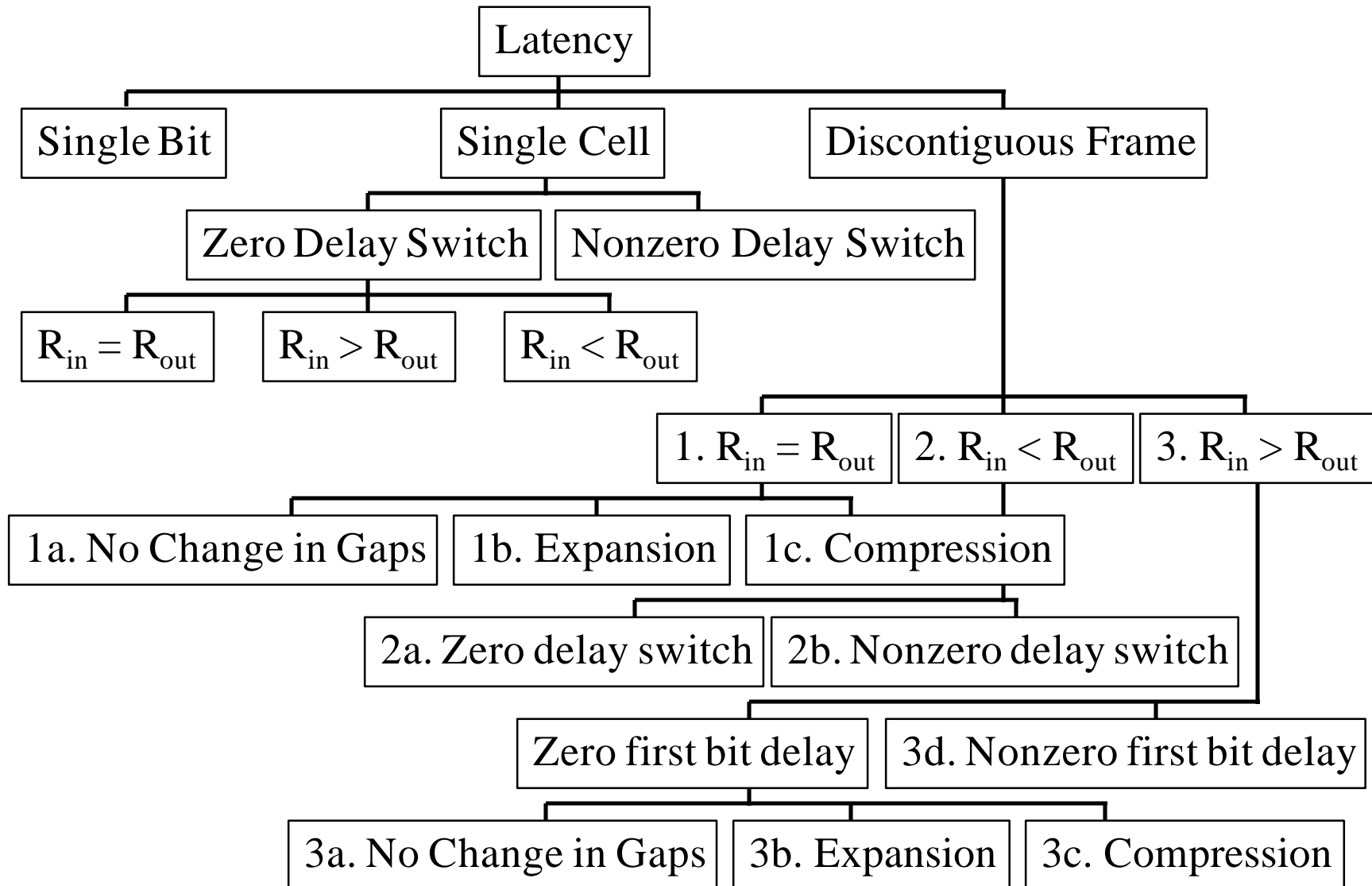
Output frame not contiguous

Input Speed \neq Output Speed

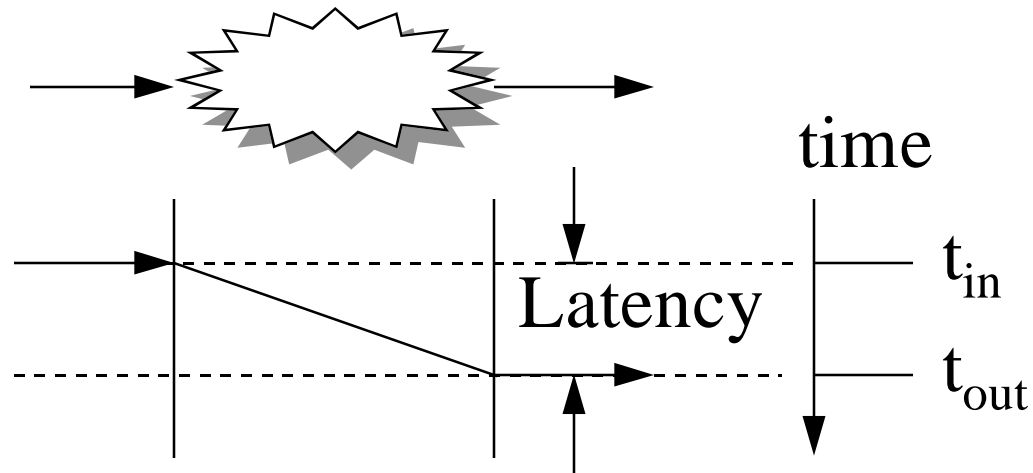
Single Cell

Single Bit

Overview: Cases To Consider

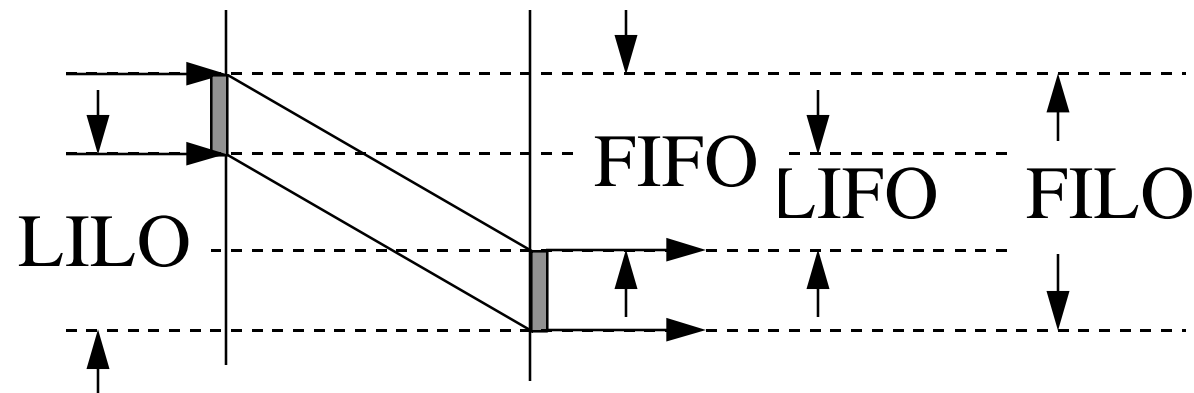


Latency: Single Bit



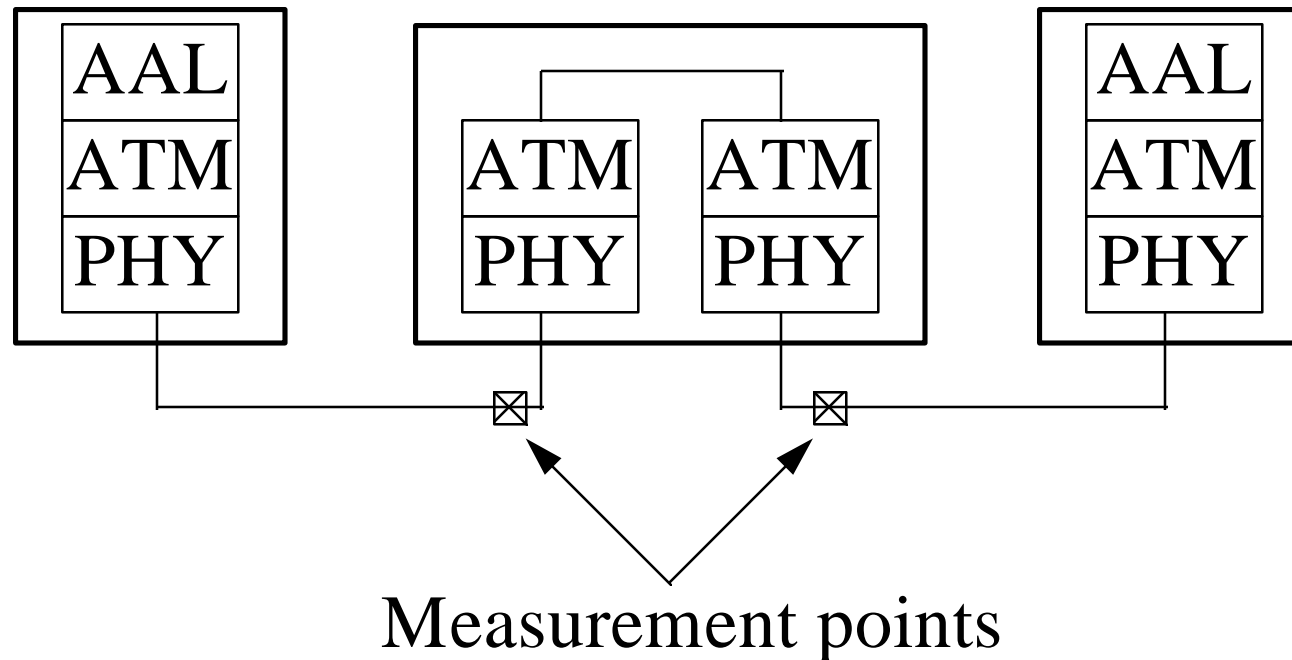
□ $\text{Latency} = t_{out} - t_{in}$

Latency: Single Cell



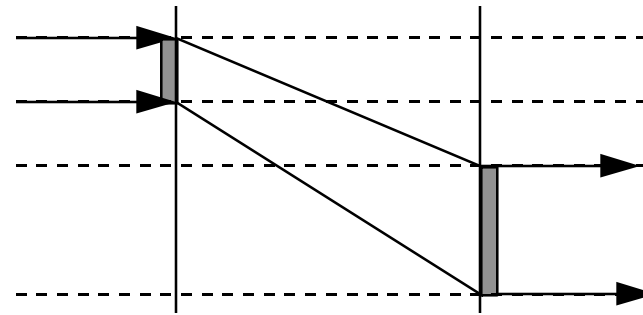
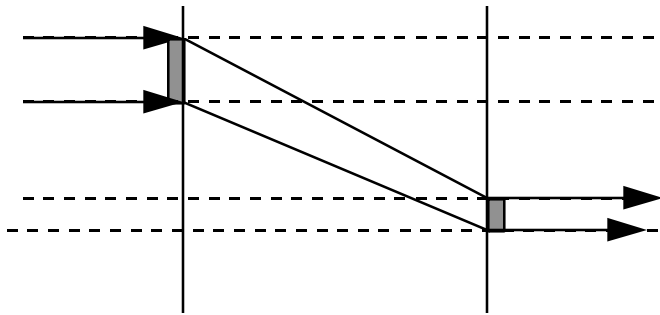
- ❑ FIFO = First-bit in to first-bit out
- ❑ LIFO = Last-bit in to last-bit out
- ❑ FILO = First-bit in to last-bit out
- ❑ LILO = Last-bit in to last-bit out
- ❑ $\text{FIFO} = \text{LILO} = \text{FILO} - \text{Cell time} = \text{LIFO} + \text{Cell time}$
- ❑ Assumes input speed = output speed

Measurement Points



- ❑ Host speed should not affect the measured switch performance
- ❑ Delay caused by input/output link speeds should not be attributed to switch latency.

Latency: Single Cell, Input Speed \neq Output Speed

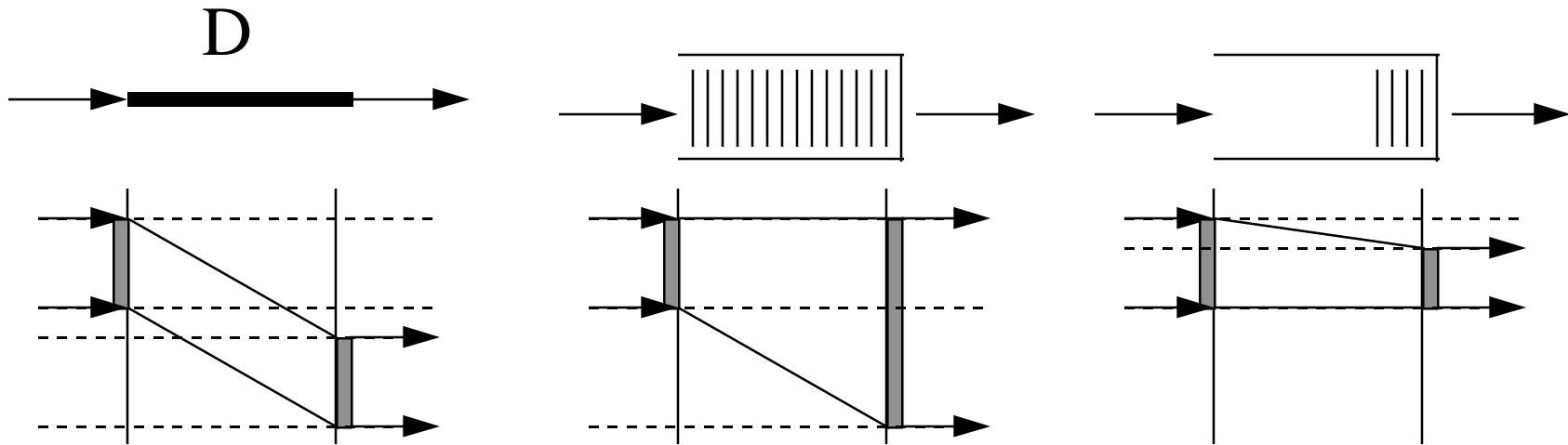


(a) Input speed $<$ Output speed (b) Input speed $>$ Output speed

- ❑ FIFO = FILO - Cell output time
- ❑ LILO = FILO - Cell input time
- ❑ LIFO = FILO - (Cell input time + Cell output time)
- ❑ We will show that MIMO is the correct switch latency

$$\text{MIMO} = \text{Min}\{\text{LILO}, \text{FILO} - \text{Cell Input Time} * R_{\text{in}}/R_{\text{out}}\}$$

Simple Switches



(a) Wire: $R_{in} = R_{out}$

(b) FIFO: $R_{in} > R_{out}$

(c) Intelligent FIFO:

$$R_{in} < R_{out}$$

□ Intelligent FIFO:

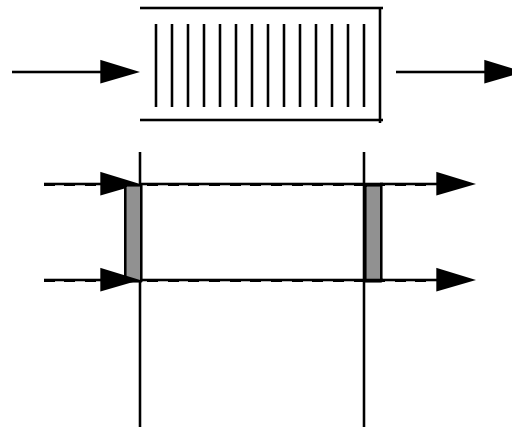
Knows cell size. Holds first bit to avoid underrun.

□ These components have known switching latencies

□ Combinations of these \Rightarrow Known latency switches

Zero-Delay Switch

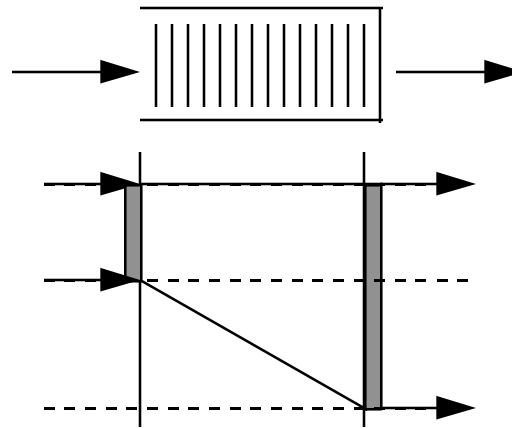
Input Speed = Output Speed



- ❑ FIFO is zero \Rightarrow Correct
- ❑ LILO is zero \Rightarrow Correct
- ❑ MIMO = $\text{Min}\{\text{LILO}, \text{FILO} - \text{Cell input time} * R_{\text{in}}/R_{\text{out}}\}$
 $= 0 \Rightarrow$ Correct

Zero-Delay Switch

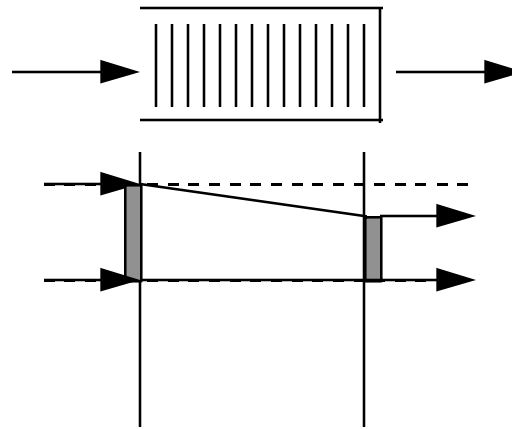
Input Speed > Output Speed



- ❑ FIFO is zero \Rightarrow Correct
- ❑ LILO is non-zero \Rightarrow Incorrect
- ❑ MIMO = $\text{Min}\{\text{LILO}, \text{FILO} - \text{Cell input time} * R_{\text{in}}/R_{\text{out}}\}$
 $= 0 \Rightarrow$ Correct

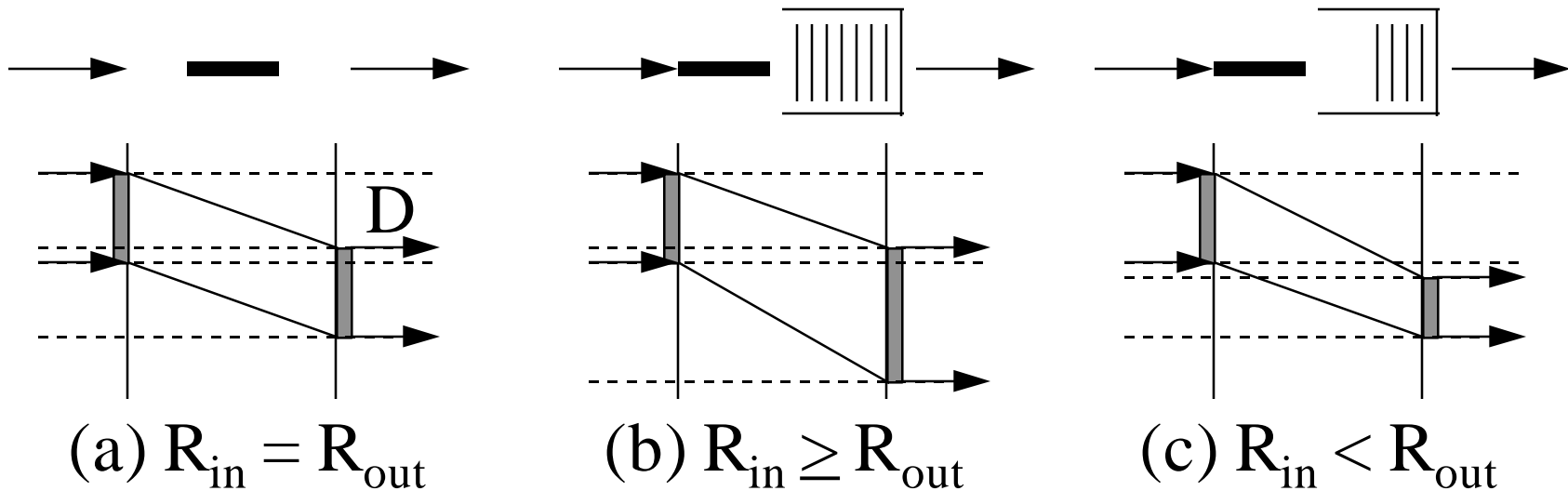
Zero-Delay Switch

Input Speed < Output Speed



- ❑ FIFO is non-zero \Rightarrow Incorrect
- ❑ LILO is zero \Rightarrow Correct
- ❑ MIMO = $\text{Min}\{\text{LILO}, \text{FILO} - \text{Cell input time} * R_{\text{in}}/R_{\text{out}}\}$
 $= 0 \Rightarrow$ Correct

Non-Zero Delay Switches



(a) FIFO = LILO = MIMO = D

(b) FIFO = MIMO = D, LILO is incorrect

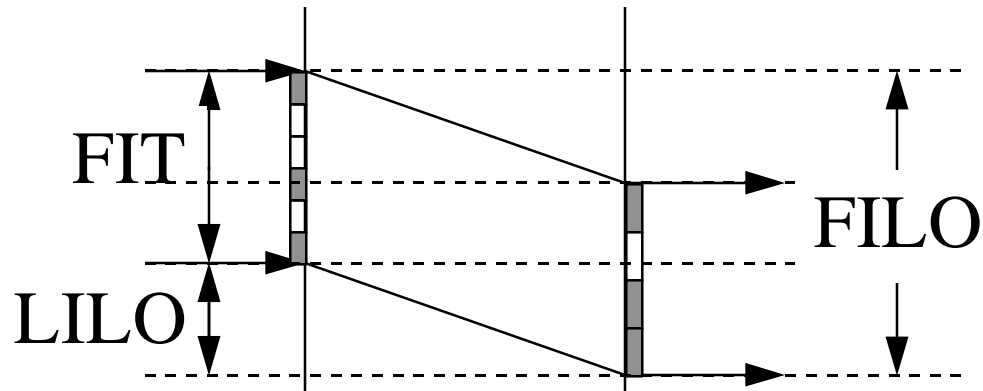
(c) LILO = MIMO = D, FIFO is incorrect

Summary: Single Cell

No.	Case	FIFO	LILO	MIMO
1	Input speed = output speed	√	√	√
2	Input speed \geq output speed	√	×	√
3	Input speed < output speed	×	√	√

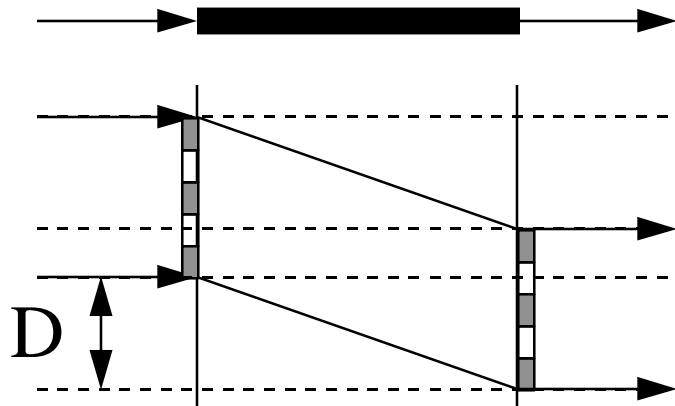
- ❑ MIMO is the only metric that applies to all cases.
- ❑ These results also apply to contiguous frames

Discontiguous Frames

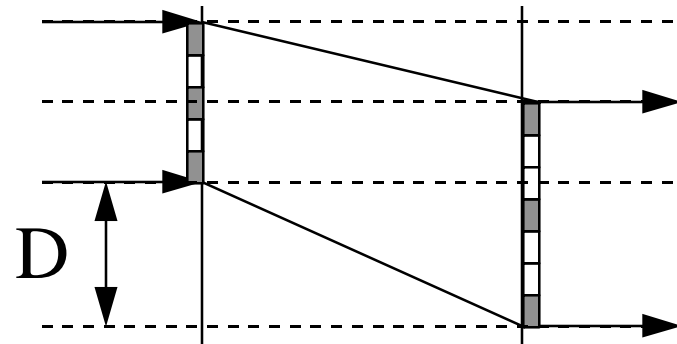


- ❑ Frames coming in and out of a switch are not contiguous
- ❑ Position and number of gaps may change
- ❑ $MIMO = \text{Min} \{ LILO, FIT * R_{in} / R_{out} \}$
Where, FIT = Frame input time
= First-bit in to last-bit in

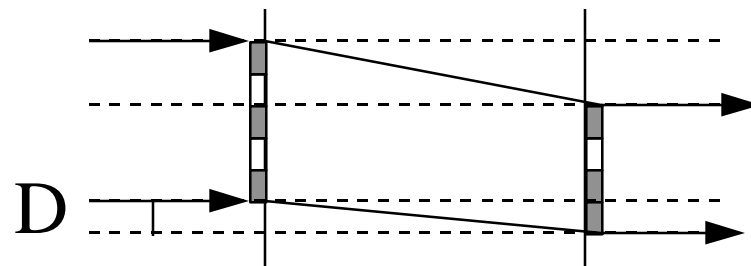
1. Input Speed = Output Speed



(a) No change

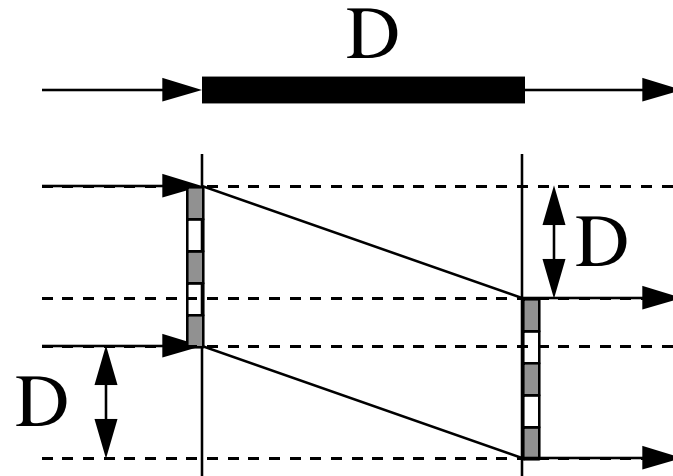


(b) Expansion



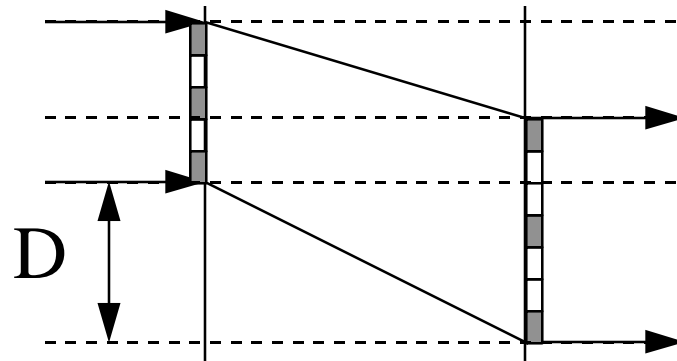
(c) Compression

1a. Input Speed = Output Speed No Change in Gaps



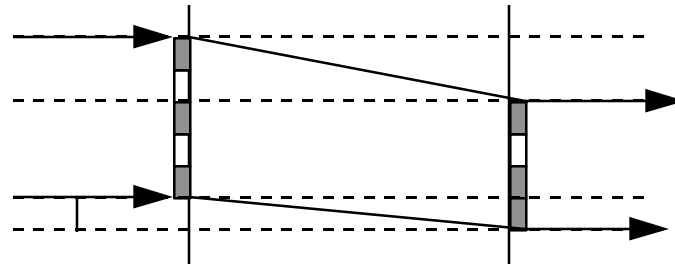
- ❑ $\text{FIFO} = D$
- ❑ $\text{LILO} = D$
- ❑ $\text{FILO} - \text{FIT} = \text{FIFO} = D$
 $\Rightarrow \text{MIMO} = \text{Min}\{\text{LILO}, \text{FILO-FIT}\} = D$
- ❑ All three metrics are correct

1b. Input Speed = Output Speed Expansion in Gaps



- ❑ FIFO does not reflect expansion.
⇒ FIFO is incorrect.
- ❑ $\text{LILO} = \text{FILO} - \text{FIT} = \text{FIFO} + \text{expansion} = D$
⇒ $\text{MIMO} = \text{Min}\{\text{LILO}, \text{FILO-FIT}\} = D$
- ❑ LILO and MIMO are correct.

1c. Input Speed = Output Speed Compression in Gaps



- ❑ FIFO does not reflect compression.
⇒ FIFO is incorrect.
- ❑ LILO = FILO - FIT = FIFO - compression = D
⇒ MIMO = $\text{Min}\{\text{LILO}, \text{FILO-FIT}\} = D$
- ❑ LILO and MIMO are correct.

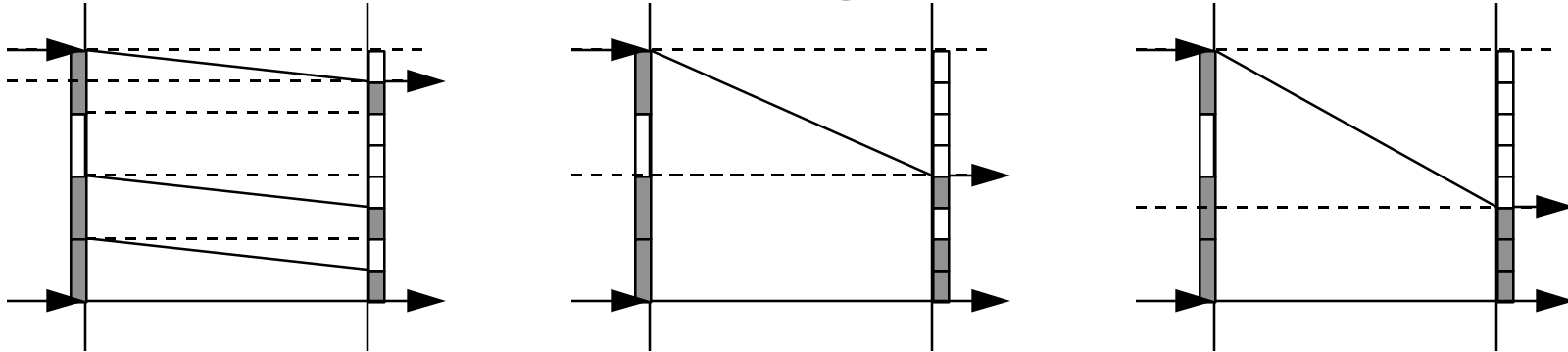
Summary: Discontiguous Frames

Input Speed = Output Speed

No.	Case	FIFO	LILO	MIMO
1a	No Change in gaps	√	√	√
1b	Expansion	×	√	√
1c	Compression	×	√	√

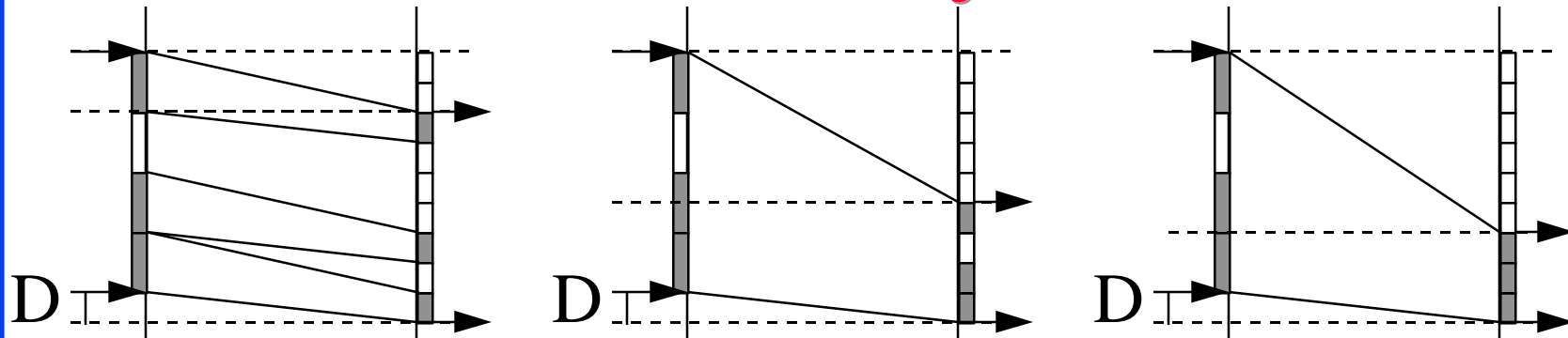
- MIMO is the only metric that applies to all cases so far.

2a. Input Speed < Output Speed Zero-Delay Switch



- ❑ Need to store bits to avoid underrun
- ❑ In the best case, last bits of each cell has no delay
 - ❑ FIFO is non-zero \Rightarrow FIFO is incorrect.
 - ❑ LILO = 0 \Rightarrow LILO is correct
 - ❑ FILO = FIT \Rightarrow FILO - FIT * R_{in}/R_{out} = Positive
 \Rightarrow MIMO = Min{LILO, FILO - FIT * R_{in}/R_{out} } = 0

2b. Input Speed < Output Speed Nonzero-Delay Switch



□ In each case:

□ $\text{FIFO} > D \Rightarrow \text{FIFO}$ is incorrect.

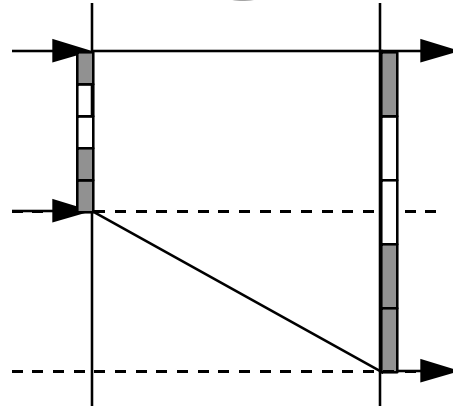
□ $\text{LILO} = D \Rightarrow \text{LILO}$ is correct

□ $\text{FILO} = \text{FIT} + D \Rightarrow \text{FILO} - \text{FIT} * R_{\text{in}} / R_{\text{out}} > D$

$\Rightarrow \text{MIMO} = \text{Min}\{\text{LILO}, \text{FILO} - \text{FIT} * R_{\text{in}} / R_{\text{out}}\} = D$

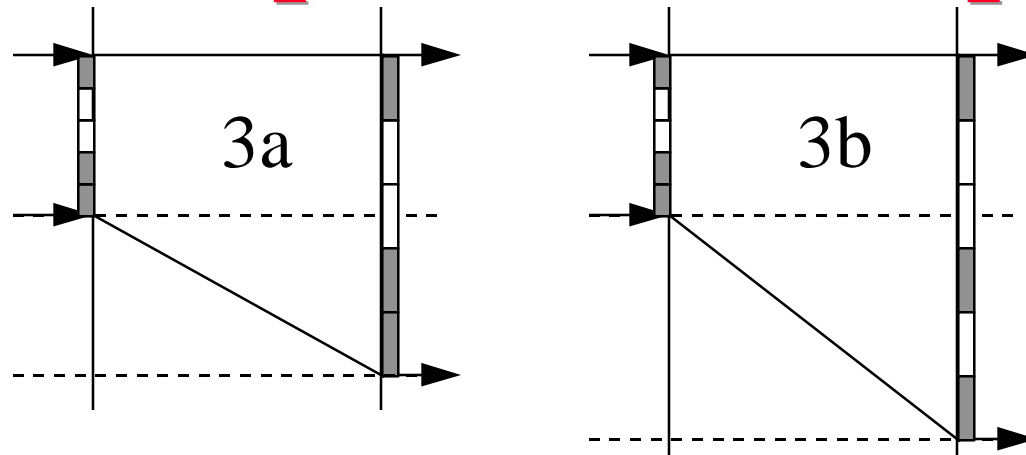


3a. Input Speed > Output Speed No Change in Gaps



- ❑ Switching delay = 0
- ❑ FIFO is zero \Rightarrow FIFO is correct.
- ❑ LILO is nonzero \Rightarrow LILO is incorrect
- ❑ $FILO = FIT * R_{in} / R_{out} \Rightarrow FILO - FIT * R_{in} / R_{out} = 0$
 $\Rightarrow MIMO = \text{Min}\{LILO, FILO - FIT * R_{in} / R_{out}\} = 0$
 MIMO is correct

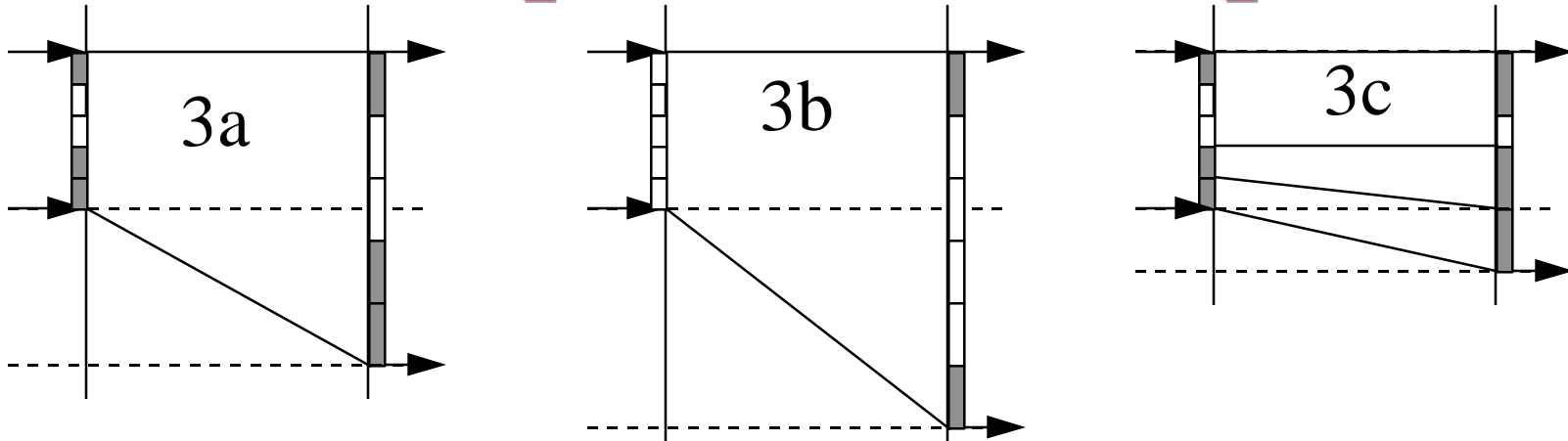
3b. Input Speed > Output Speed Expansion in Gaps



- ❑ Worse than 3a. Switching delay = Two cell input time
- ❑ FIFO is zero \Rightarrow FIFO is incorrect.
- ❑ LILO > Two cell input time \Rightarrow LILO is incorrect
- ❑ FILO > $FIT * R_{in} / R_{out} \Rightarrow FILO - FIT * R_{in} / R_{out} = 2$
 $\Rightarrow MIMO = \text{Min}\{LILO, FILO - FIT * R_{in} / R_{out}\} = 2$

MIMO is correct

3c. Input Speed > Output Speed Compression in Gaps



- ❑ This case is better than 3a by 3 cells. Switch latency = -3
- ❑ FIFO is zero \Rightarrow FIFO is incorrect.
- ❑ LILO = 2 \Rightarrow LILO is incorrect
- ❑ FILO = 7, FIT = 5,
 \Rightarrow MIMO = $\text{Min}\{\text{LILO}, \text{FILO} - \text{FIT} * R_{in}/R_{out}\} = -3$

MIMO is correct

Summary: Discontiguous Frames

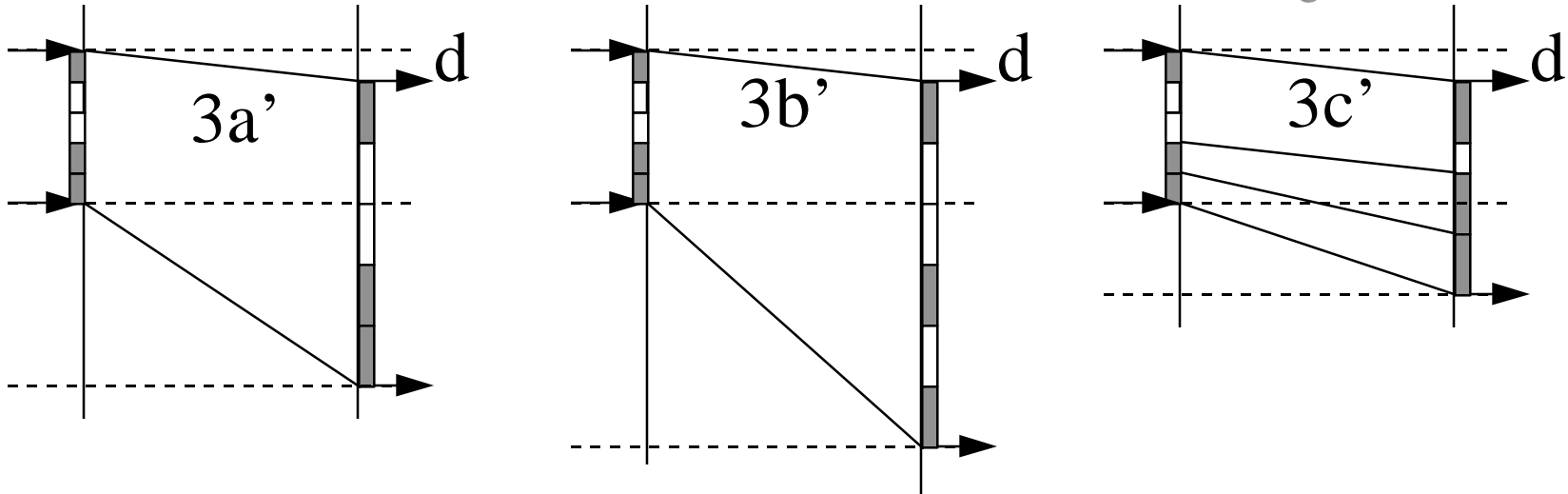
Input Speed > Output Speed

Zero First Bit Delay

No.	Case	FIFO	LILO	MIMO
3a	No Change in gaps	√	×	√
3b	Expansion	×	×	√
3c	Compression	×	×	√

- MIMO is the only metric that applies to all cases so far.

3d. Input Speed > Output Speed Nonzero First Bit Delay



- These cases are similar to 3a, 3b, 3c except that the switch delay has increased by d , where d is the first bit delay.
- It can be shown that the previous summary table applies here also.

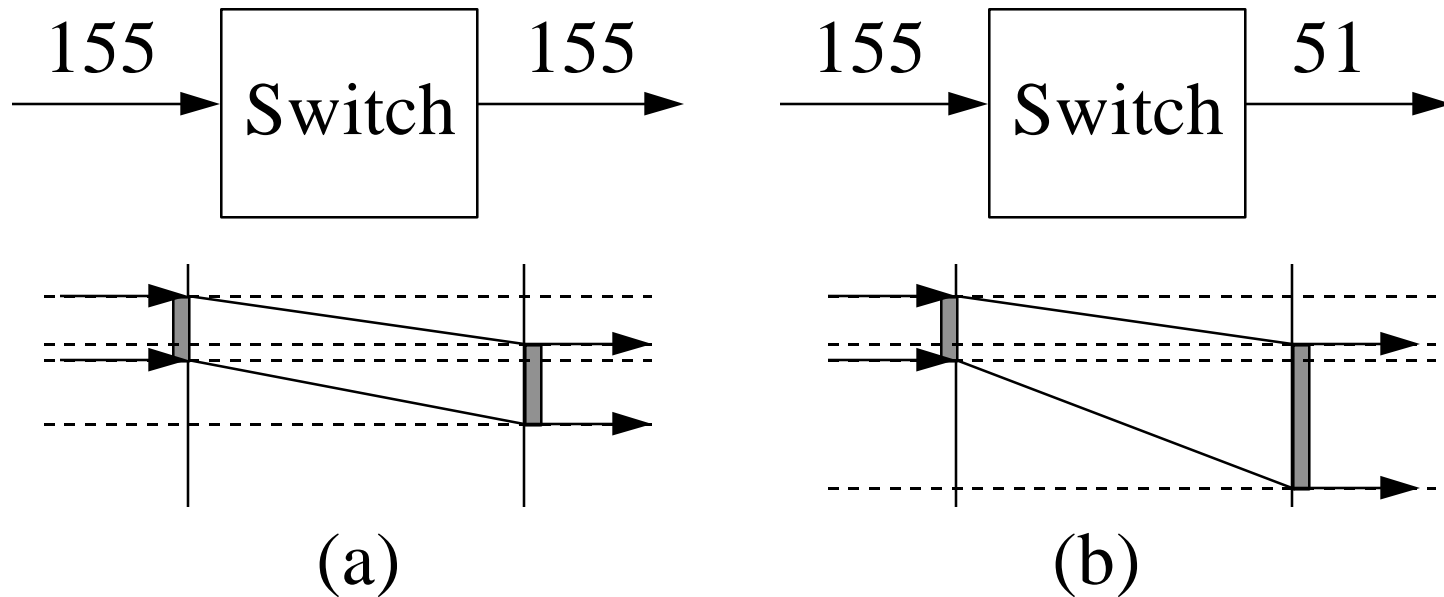
Summary: Discontiguous Frames

Input Speed > Output Speed

No.	Case	FIFO	LILO	MIMO
3a+3a'	No Change in gaps	√	×	√
3b+3b'	Expansion	×	×	√
3c+3c'	Compression	×	×	√

- MIMO is the only metric that applies to all cases.

User Perceived Delay



- ❑ The switch latency is same in both cases.
- ❑ The user perceived performance in case b is worse than that in case a.

User Perceived Performance (Cont)

- ❑ The user perceived performance depends upon the link speeds
- ❑ The switch latency measured by MIMO is independent of the input/output link speeds.
- ❑ User can not begin its work until the last bit has been received and so user perceived performance is reflected by LILO.
- ❑ The difference LILO-MIMO is due to link speed differential. This is called **buffering delay** and is nonzero only if the input has to be buffered (input speed $>$ output speed).

User Perceived Performance (Cont)

- In all other cases, buffering delay is zero (Input speed \geq output speed). In these cases,

$$\text{MIMO} = \text{LILO}.$$

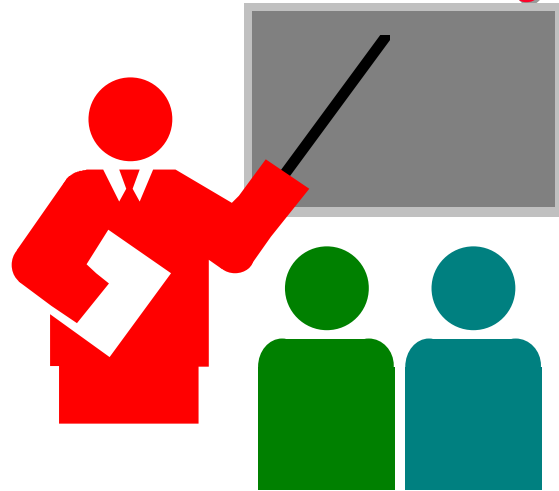
- In general:

$$\text{User Perceived Delay} = \text{LILO}$$

$$= \text{MIMO} + \text{Buffering Delay}$$

- Buffering delay and user perceived delay is never negative.
- Switches are smart and can compress a frame resulting sometimes in negative delay (when input speed $<$ output speed)

Summary



- ❑ Switch Latency:
$$\text{MIMO} = \text{Min}\{\text{LILO}, \text{FILO} - \text{FIT} * R_{\text{in}} / R_{\text{out}}\}$$
- ❑ Switch latency is not affected by host or link speeds
- ❑ User perceived delay = LILO
- ❑ Buffering delay = LILO - MIMO