October, 2019

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Why accuracy-driven markets will transform trading.

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> “That’s when I realized the markets are rigged. And I knew it had to do with the technology.”

–Brad Katsuyama, Quoted by Michael Lewis, Flash Boys

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What this talk is *NOT* about...

- Market micro-structure.
- Policy
  - Policy vs. Mechanism.

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"The markets aren't perfect. And technology can help."

–David Snowdon, STAC Summit Chicago, October 2019

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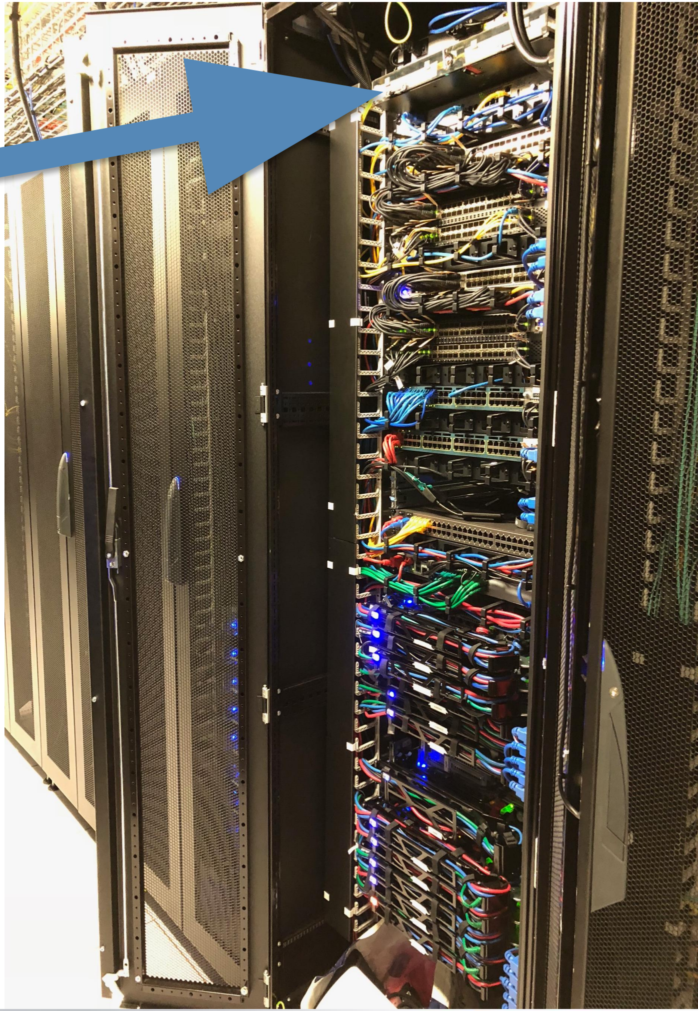
A customer’s view of an exchange...

Exchange fibres



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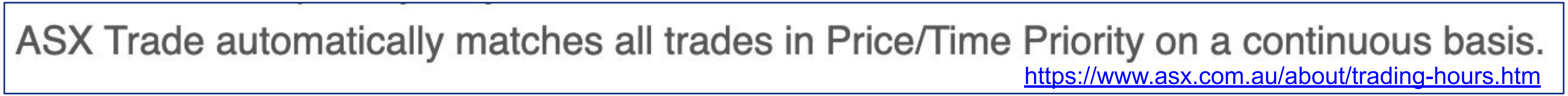
What does it mean to be fair?

- Venues should do what it says on the tin. e.g...



ASX Trade automatically matches all trades in Price/Time Priority on a continuous basis.

https://www.asx.com.au/about/trading-hours.htm

- TX: Two key “time” properties: Two equal orders, placed in a sequence, should be executed in that sequence.
  - Other policies might make more sense?
  - Traders should be isolated from one another.

- RX: Two market data feeds deemed to be equal by the venue should deliver the same information at the same time (to within stated tolerances).

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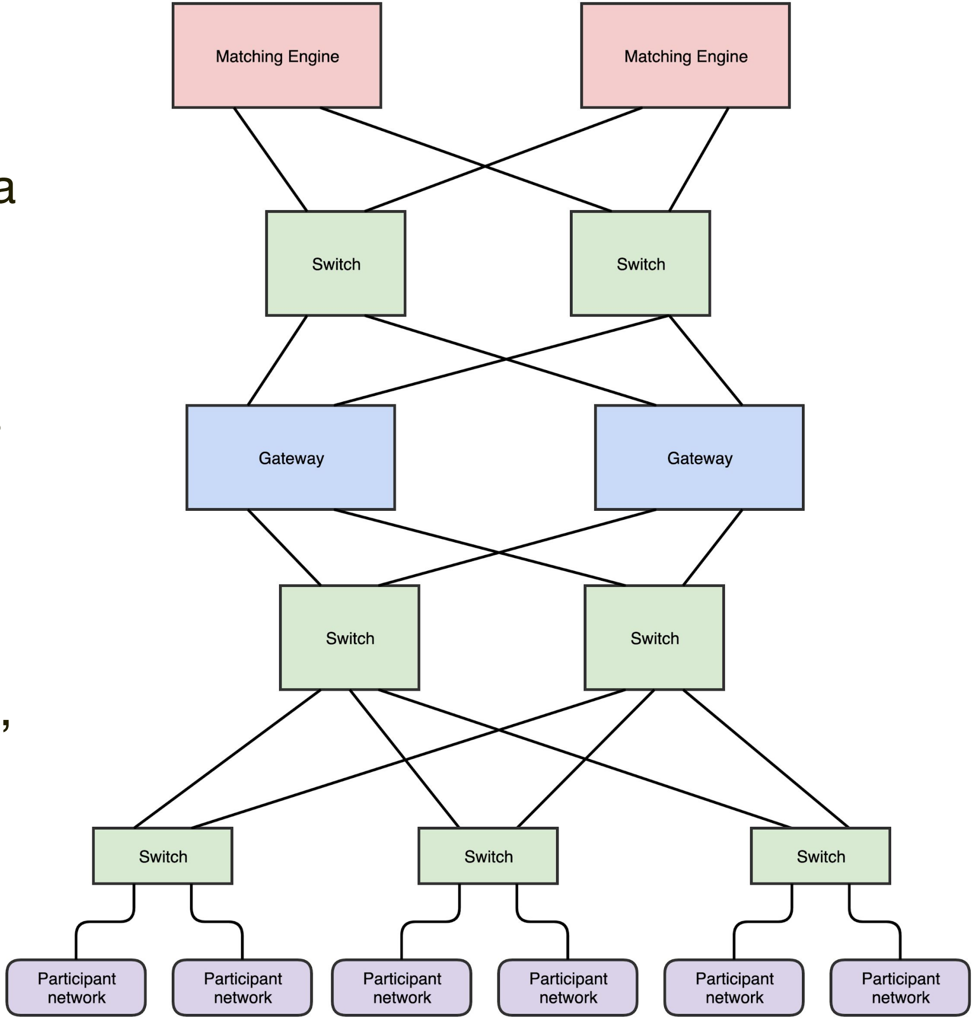
A typical exchange...

- Participants are co-located with a top-of-rack cross-connect.
- Matched-length fibres deliver messages to the exchange.
- An L3 network with BGP delivers unicast traffic for orders.
- Market data is delivered via sparse multicast (PIM).
- Gateways process this, manage sessions, check for order validity, route to matching engines.
- Matching engines manage the books, match orders, and generate data.



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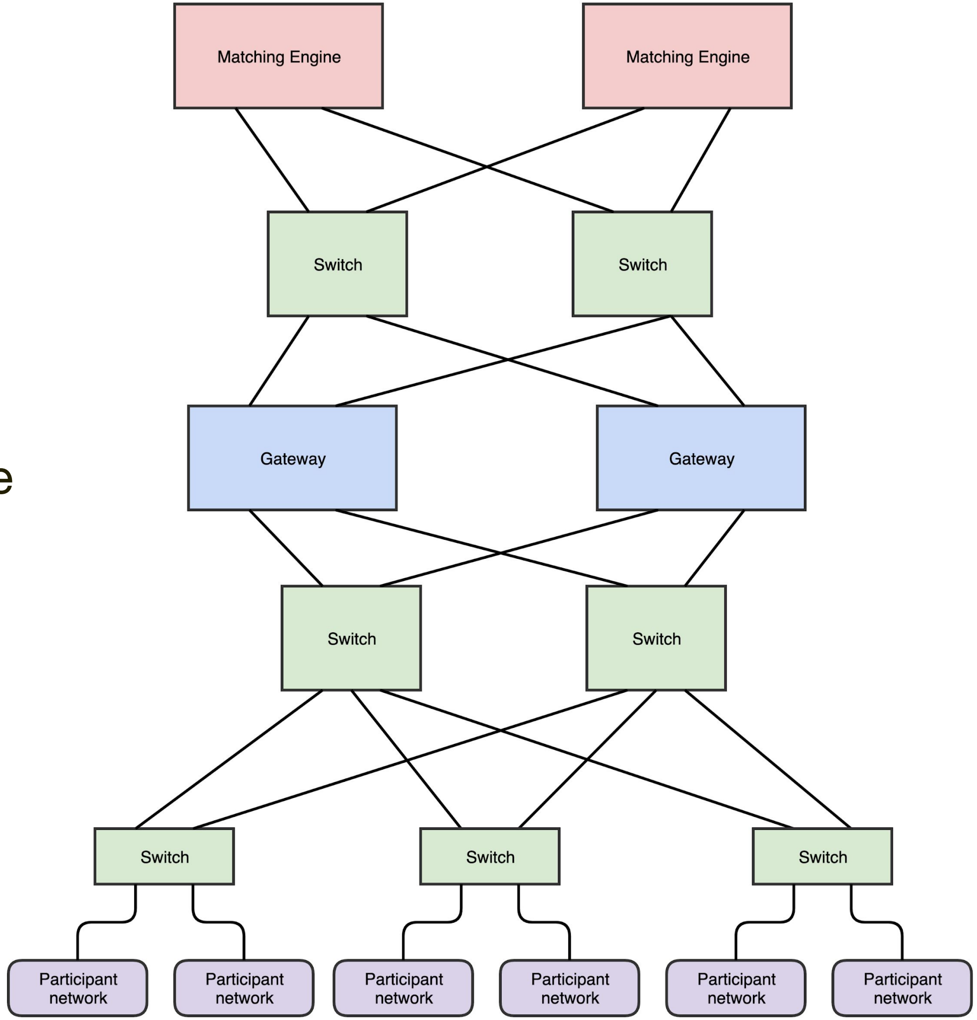
Typical issues

- Multiple gateways -- each gateway gets uneven load, so takes more or less time -- Venue moves to a single gateway?

- Individual switches may get more load, and therefore more contention queuing -- Trader connects to all the switches, monitors load, places orders? Avoids adverse selection?

- Sources of load -- different traders, sparse multicast.



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Sequencing point

- Sequencing point -- the place where the execution order is fixed.
- By default, the sequencing point is usually at the hand-off to the matching engine software.
  - Note: this is, by definition, store-and-forward.
  - Software usually executes once it’s received the *entire* order message.
- Going with a single gateway (can) move the sequencing point
  - Dependent on gateway implementation

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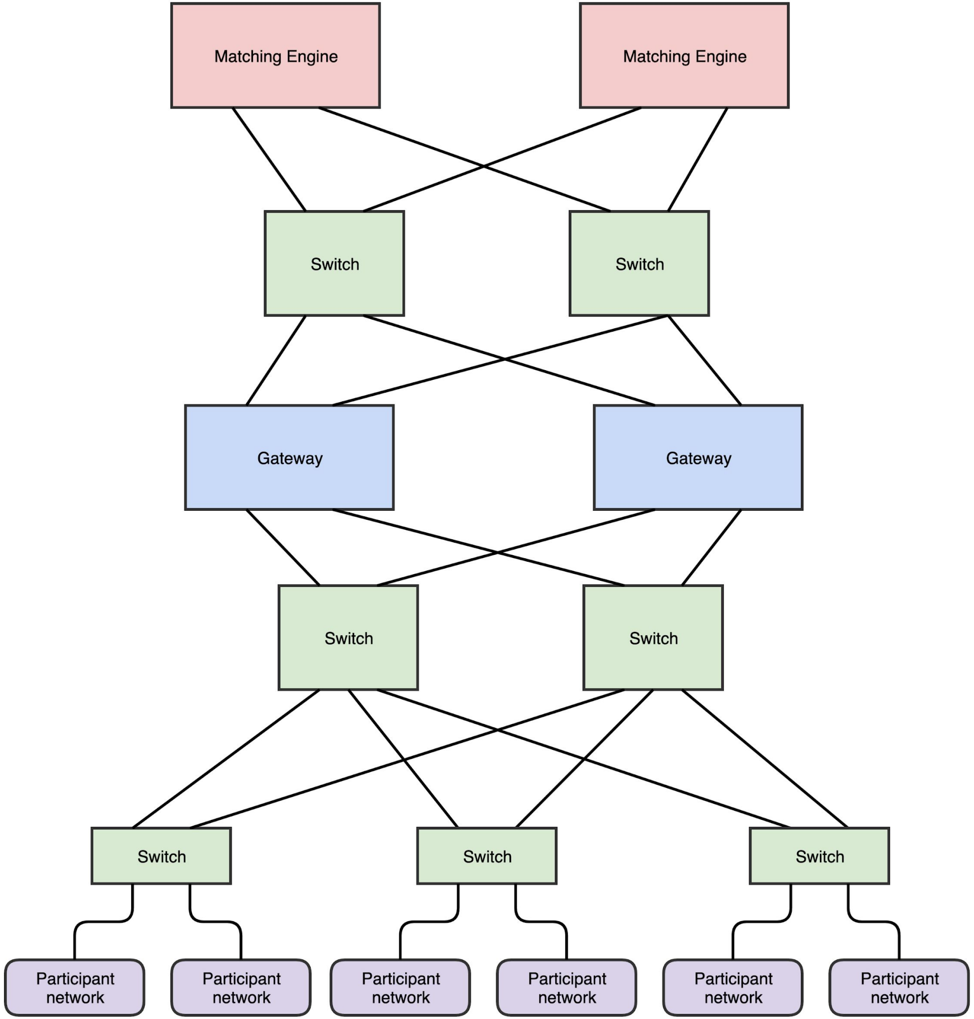
Typical issues

- Switches and gateways are not deterministic.

- Gateway network cards and network stacks do not deliver packets to software in-order.
    - Sometimes it's faster not to.
    - Use a specialised network stack like Solarflare WODA.

- Some racks are closer than others -- Equalise the length of the cross-connect fibres.



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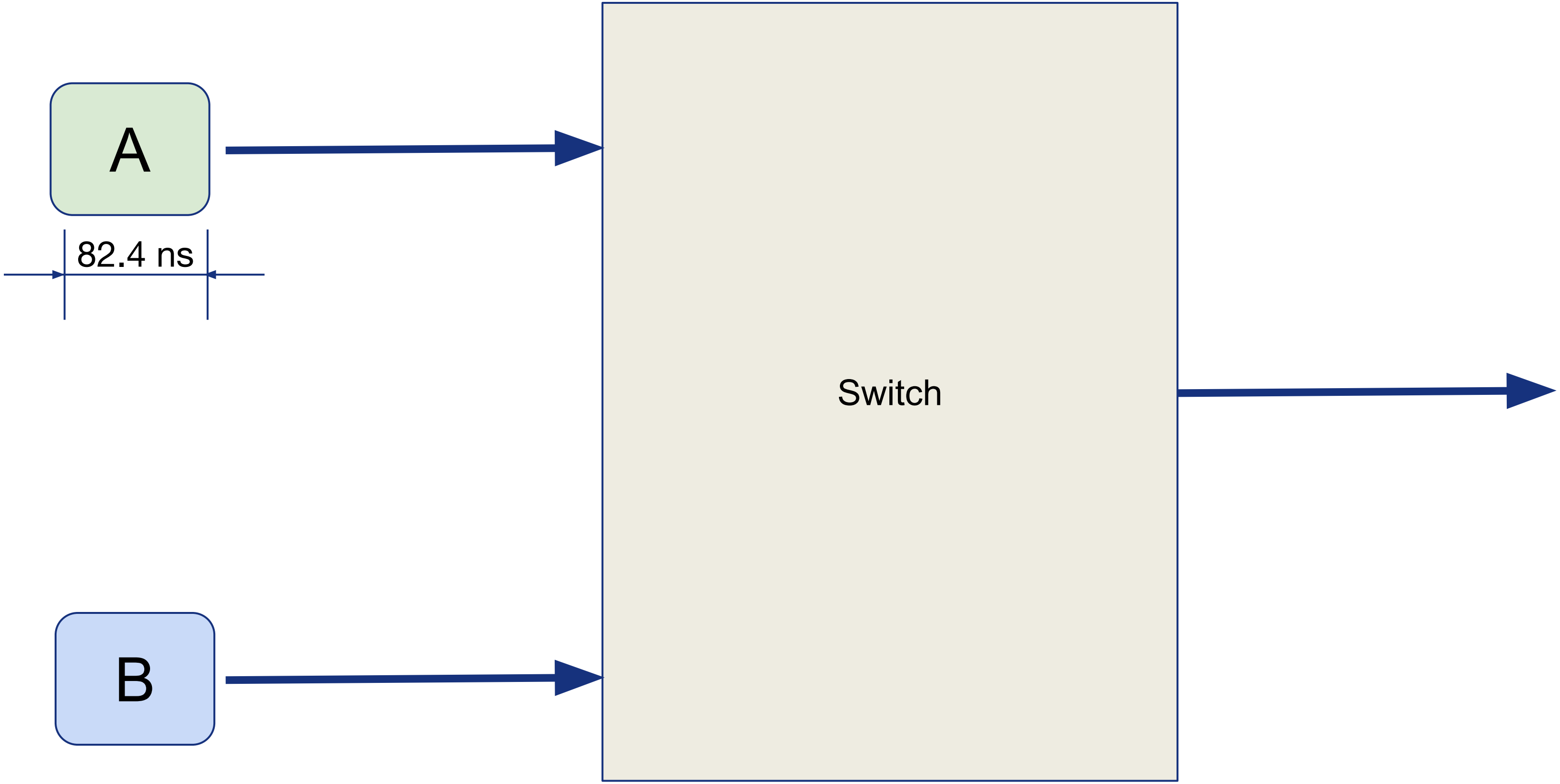
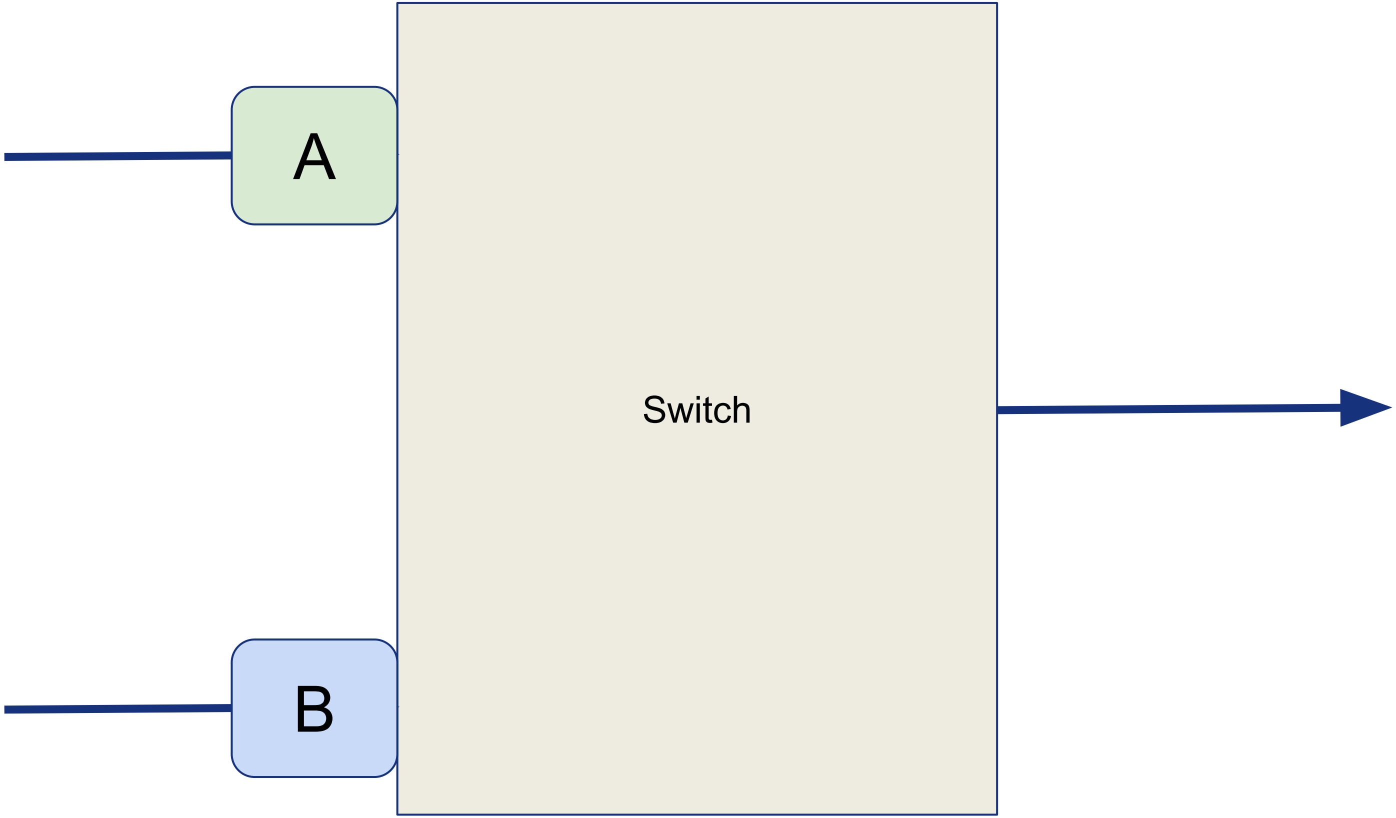
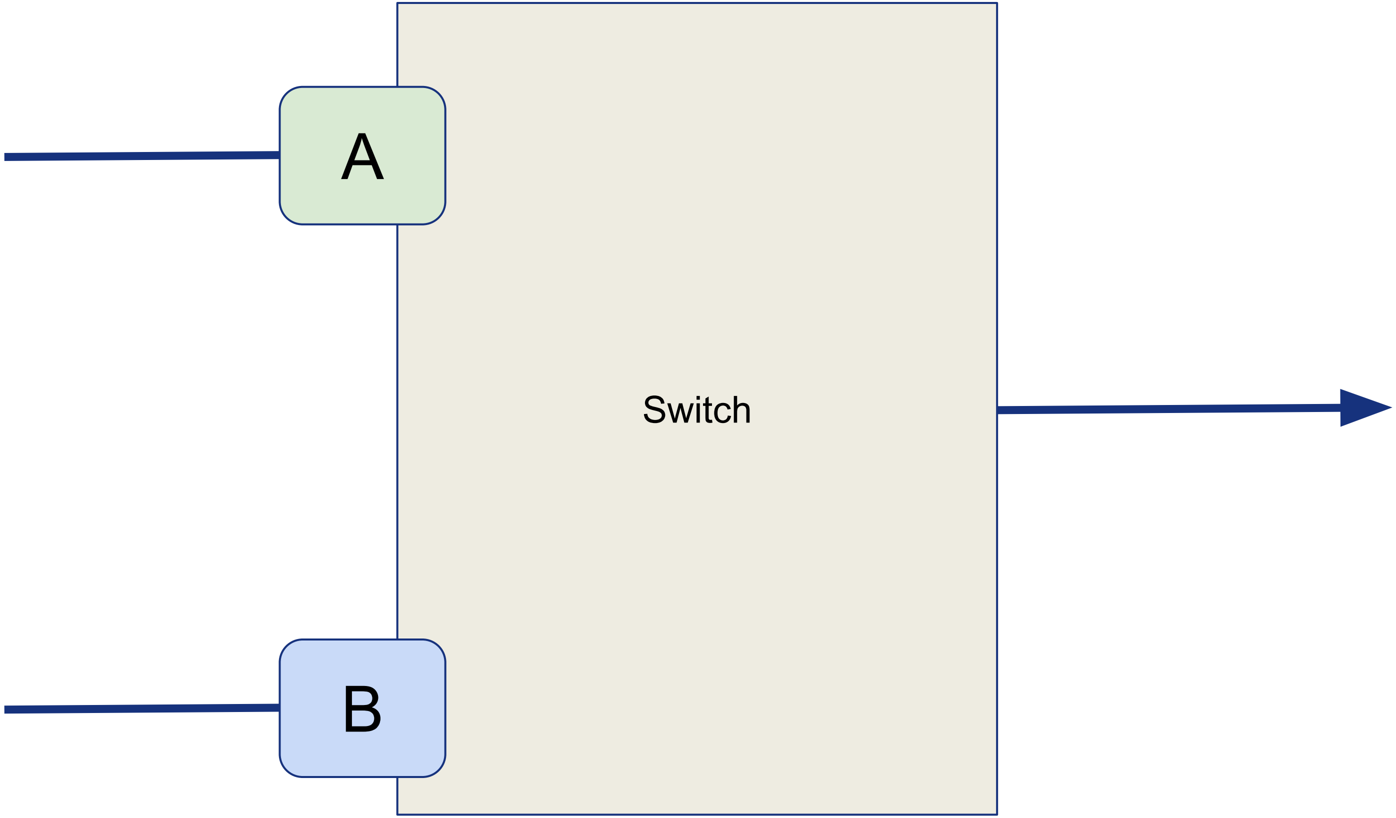


t = 0 ns



t = 300 ns



t = 330 ns

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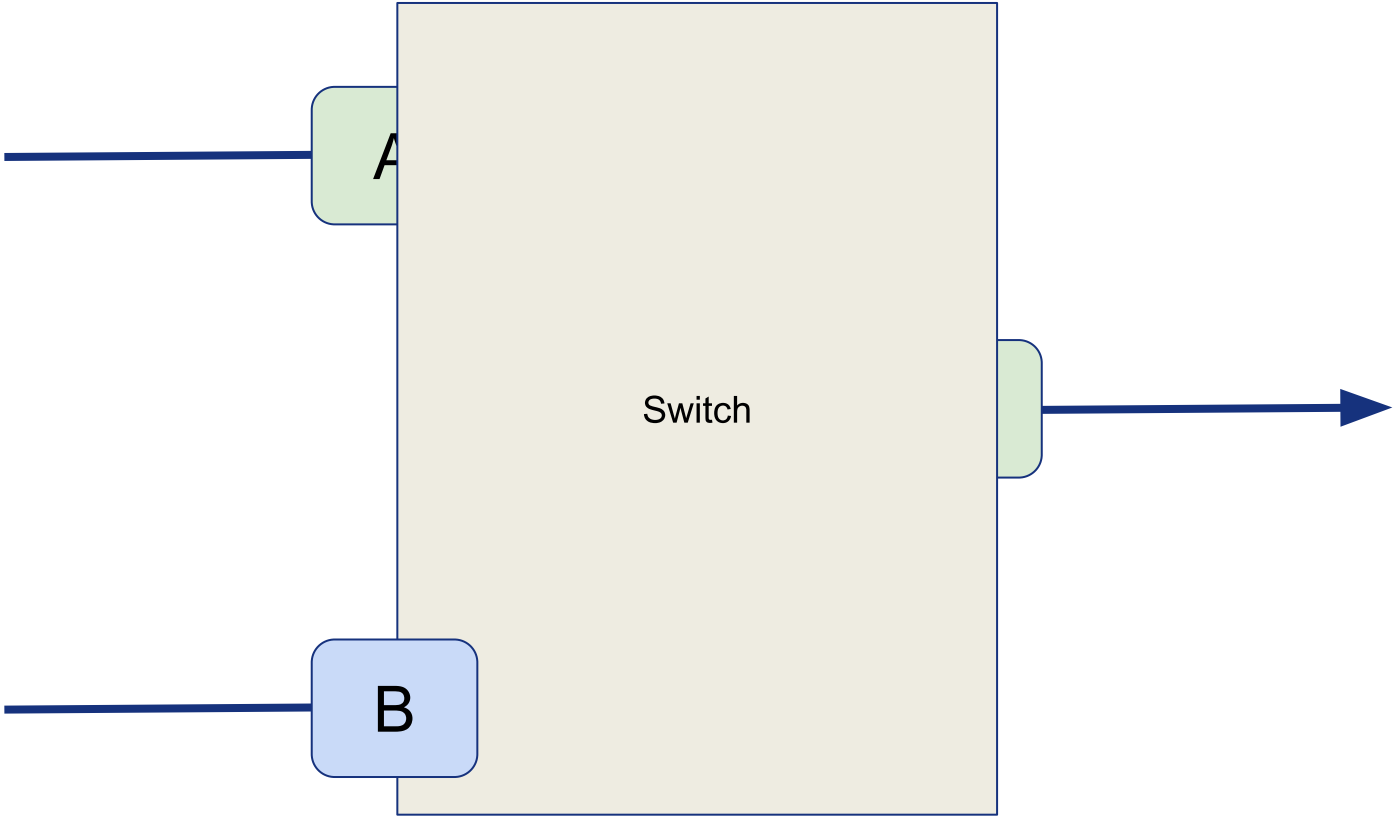

t = 350 ns

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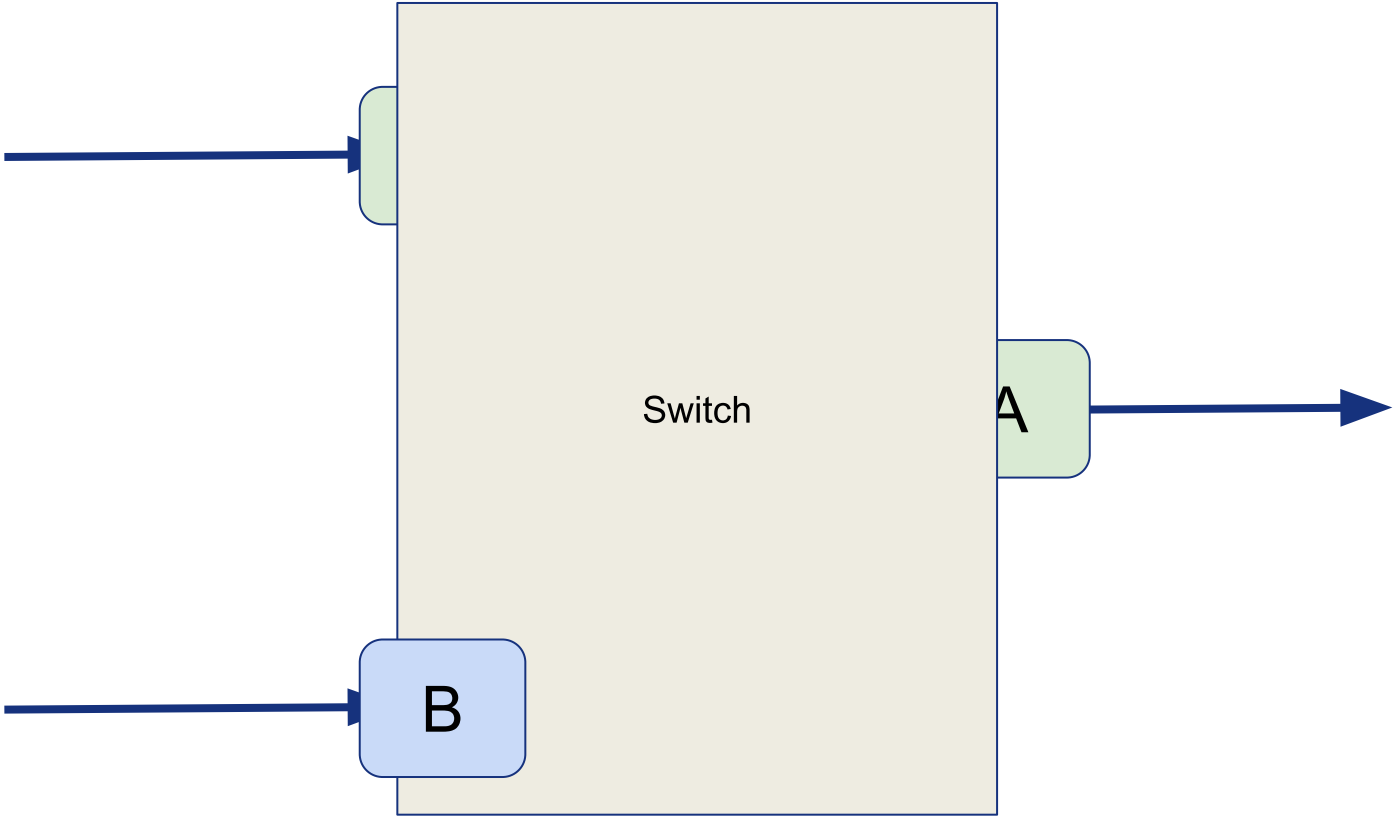
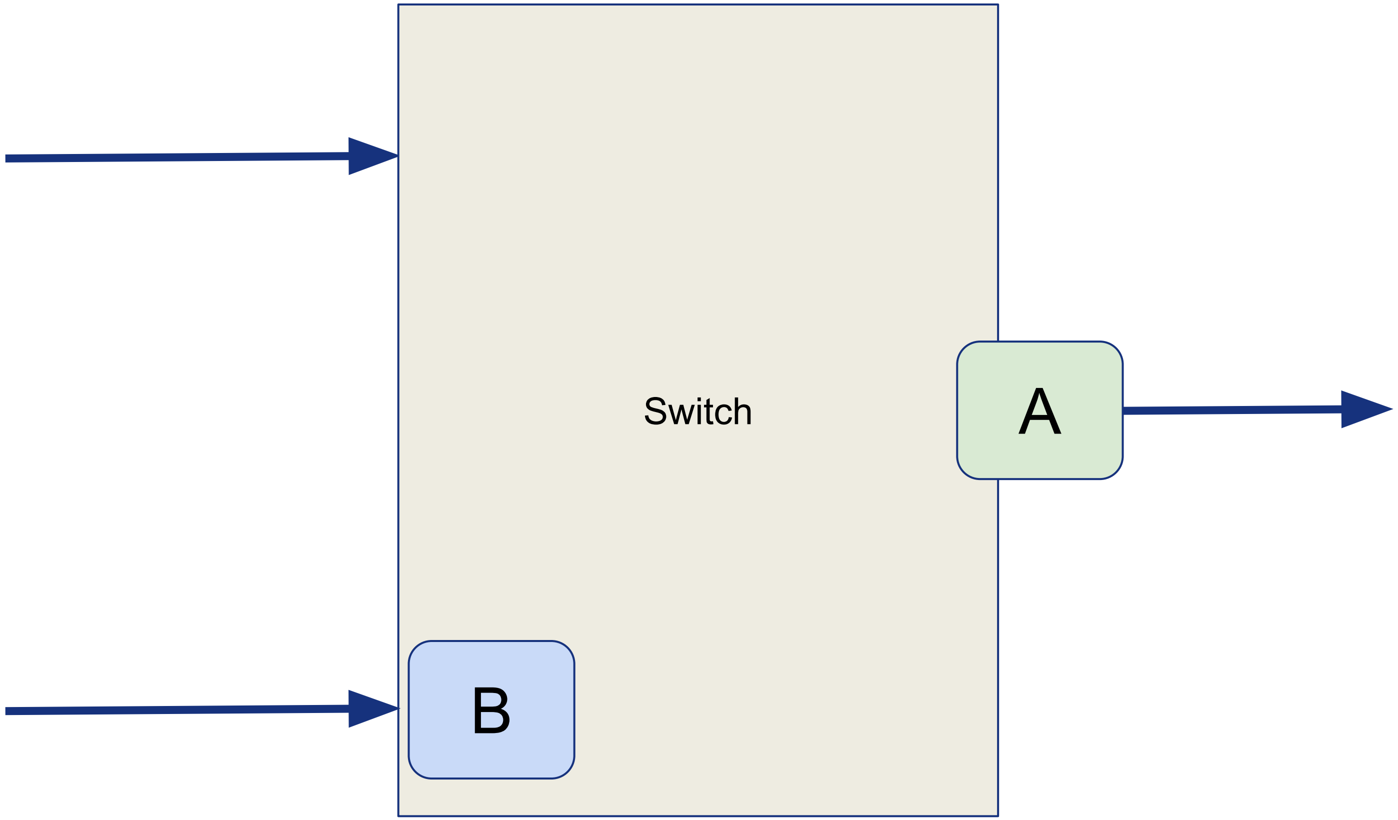
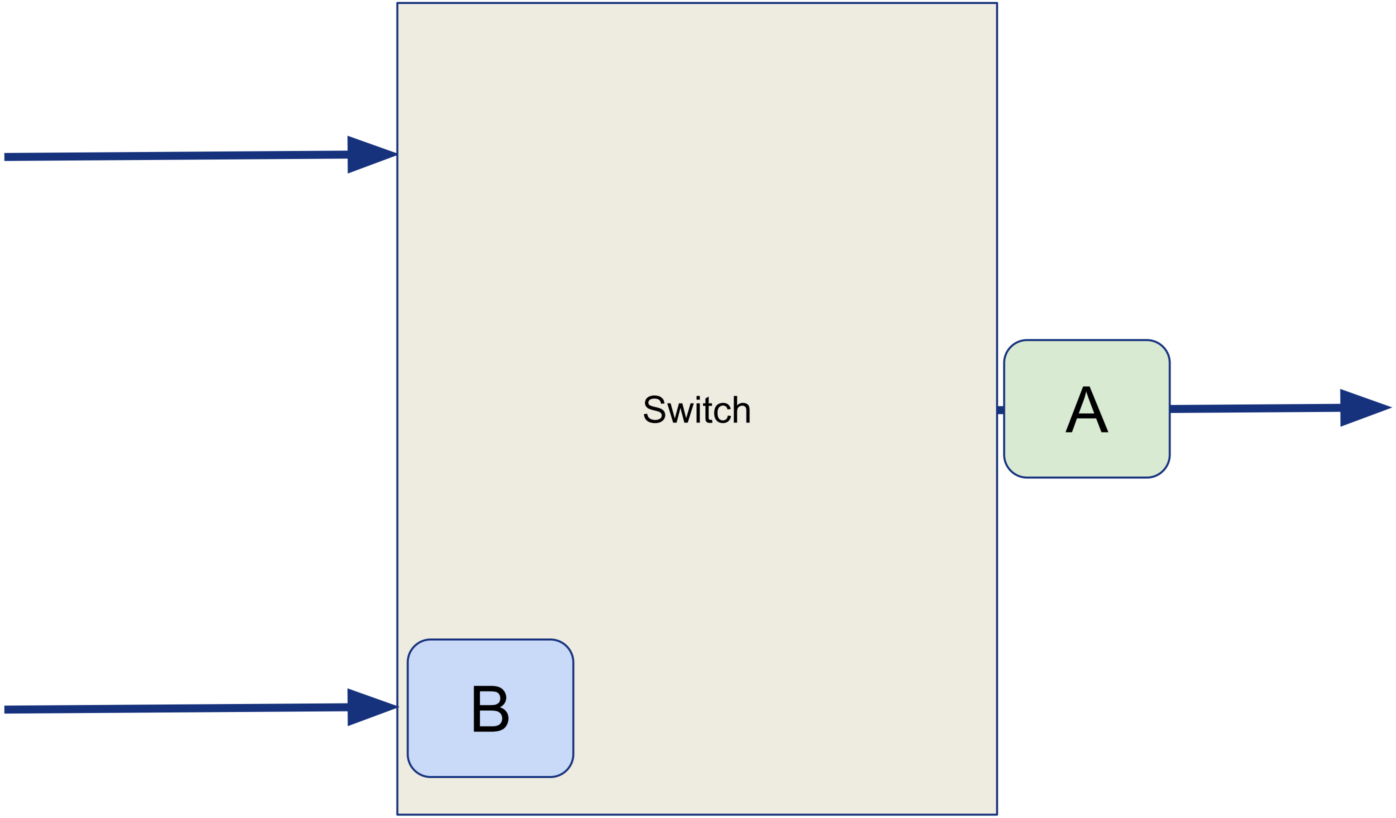


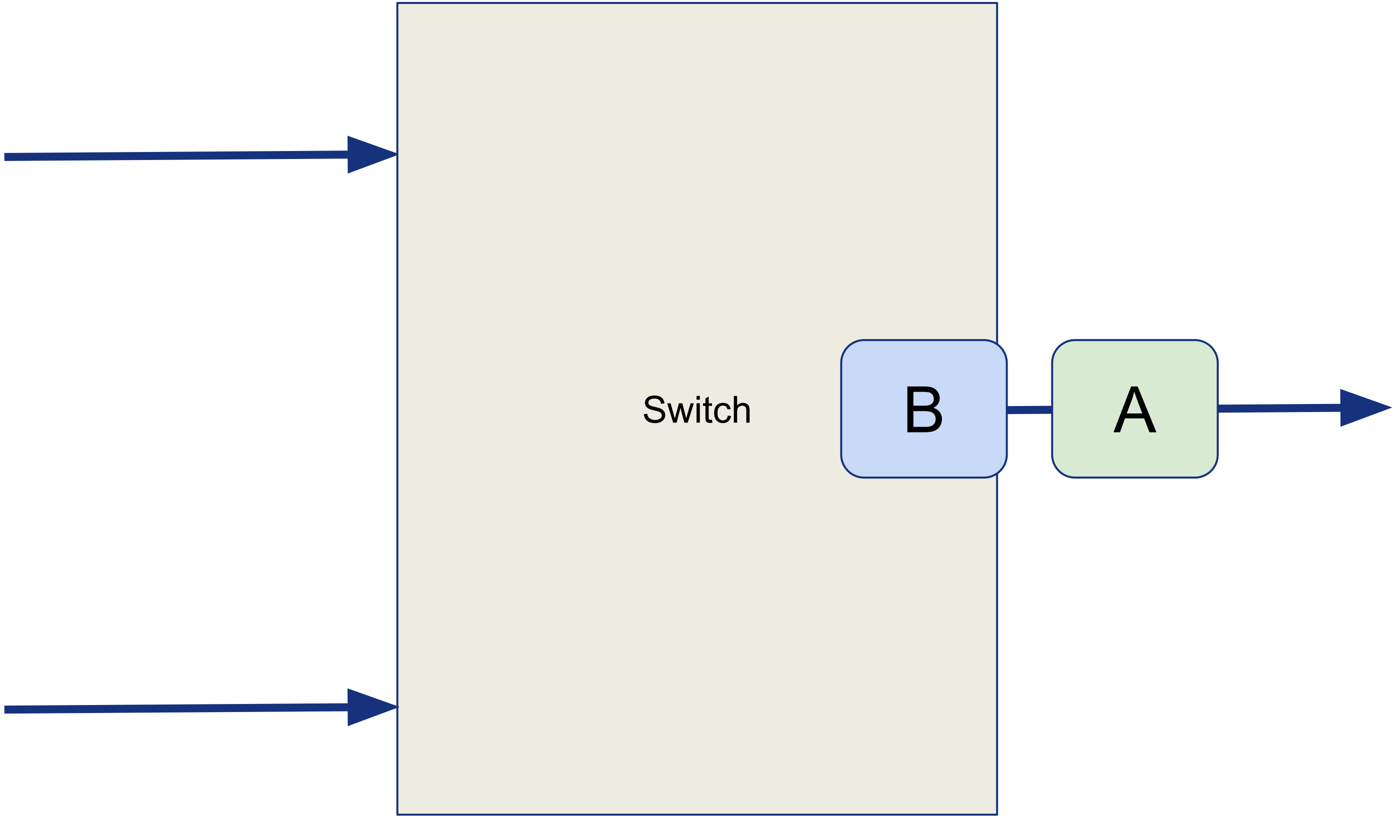
t = 370 ns



t = 382.4 ns



t = 412 ns



t = 430 ns

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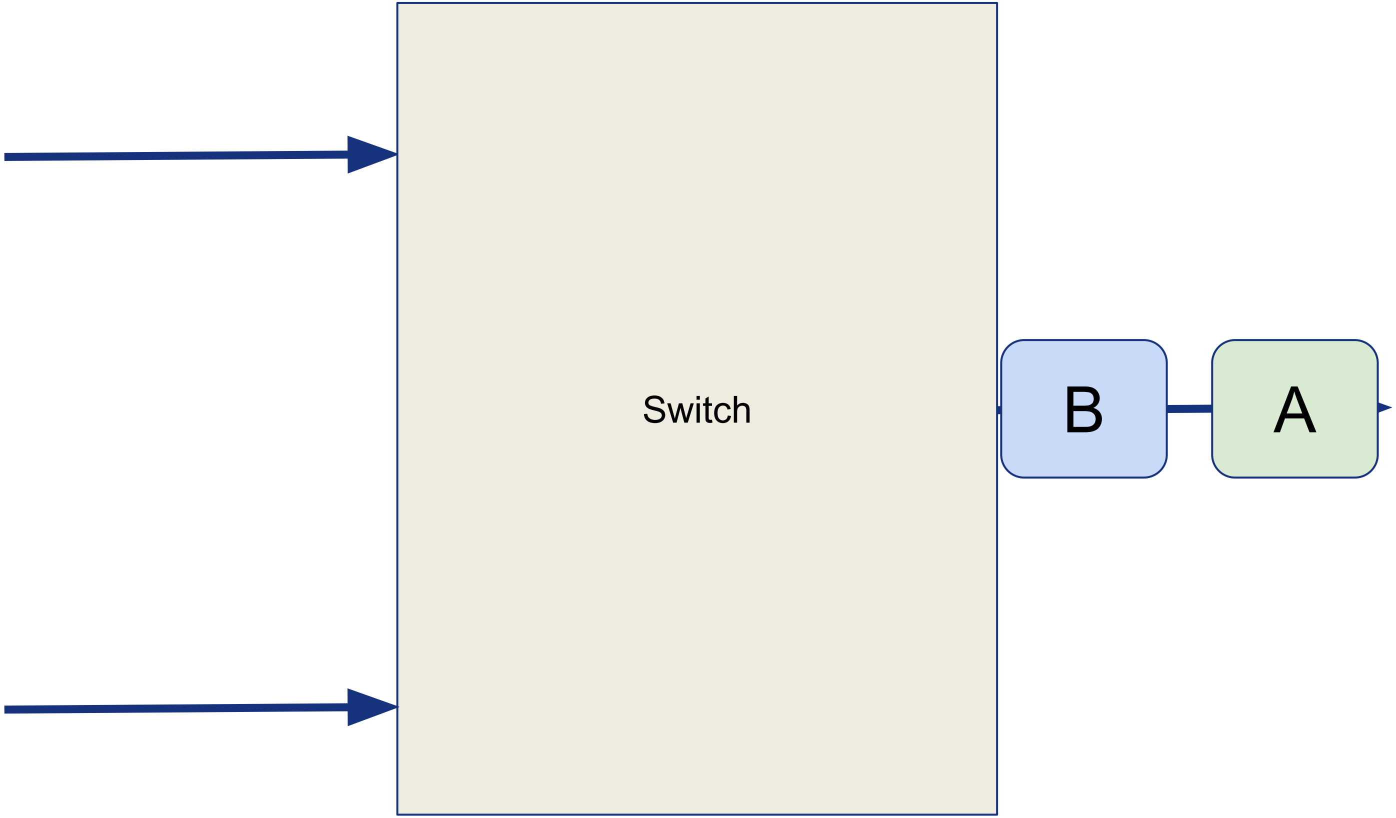

t = 494.4 ns

A

Starts to arrive:	380 ns
Finishes arriving:	462 ns

B

Starts to arrive:	480 ns
Finishes arriving:	562 ns

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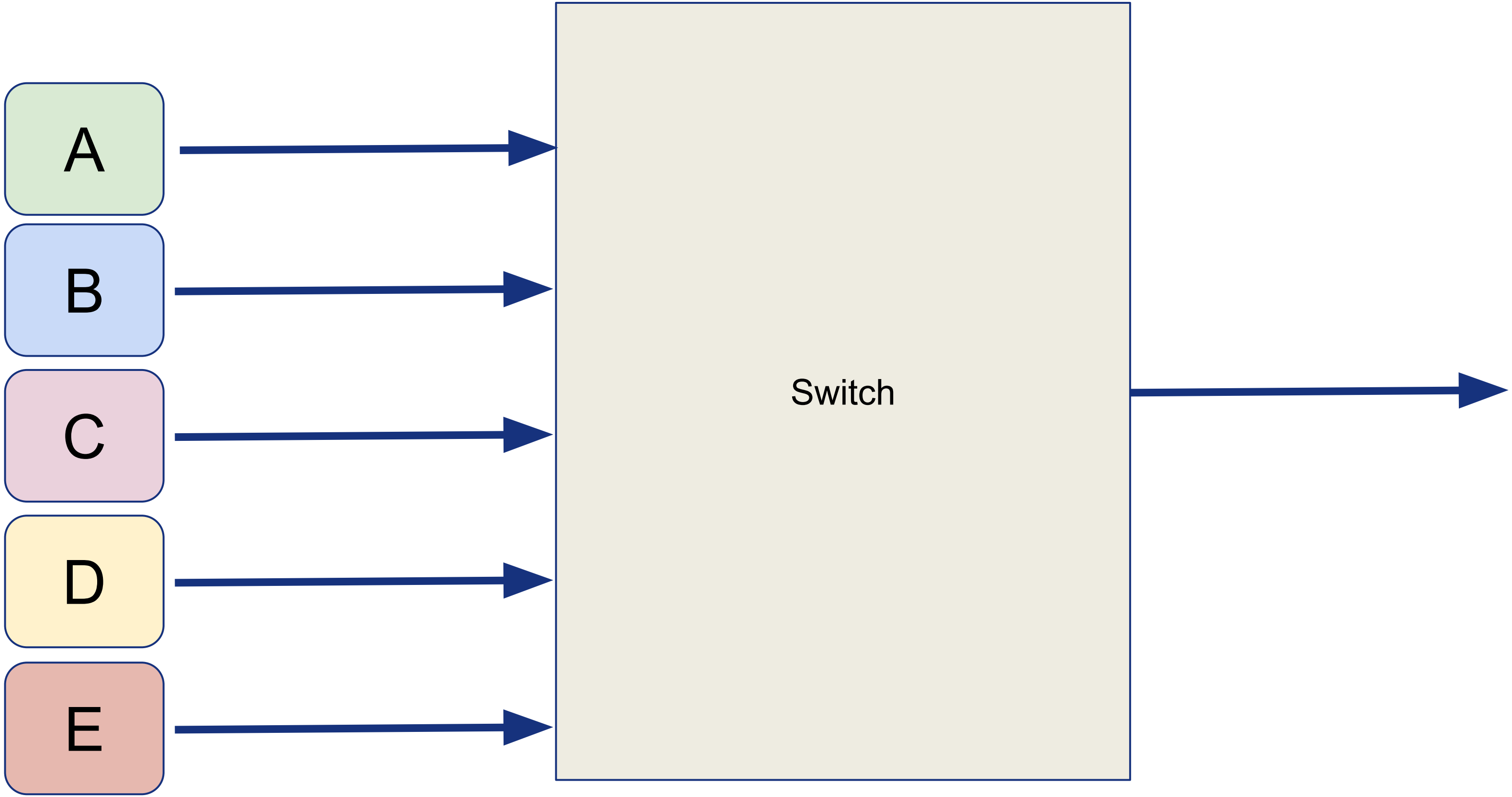

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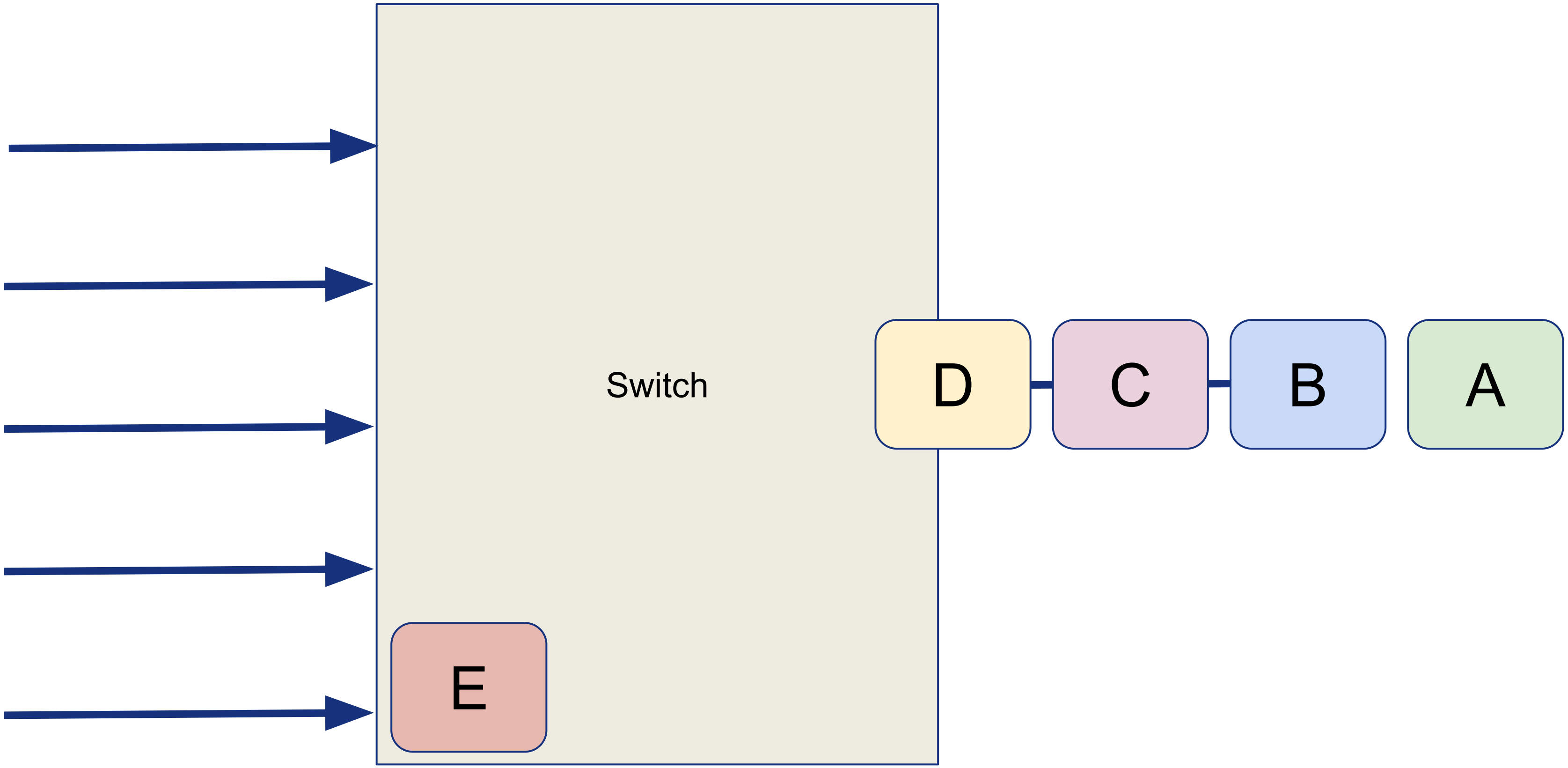

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A	Starts to arrive:	380 ns
	Finishes arriving:	462 ns
B	Starts to arrive:	480 ns
	Finishes arriving:	562 ns
C	Starts to arrive:	580 ns
	Finishes arriving:	662 ns
D	Starts to arrive:	680 ns
	Finishes arriving:	762 ns
E	Starts to arrive:	780 ns
	Finishes arriving:	862 ns

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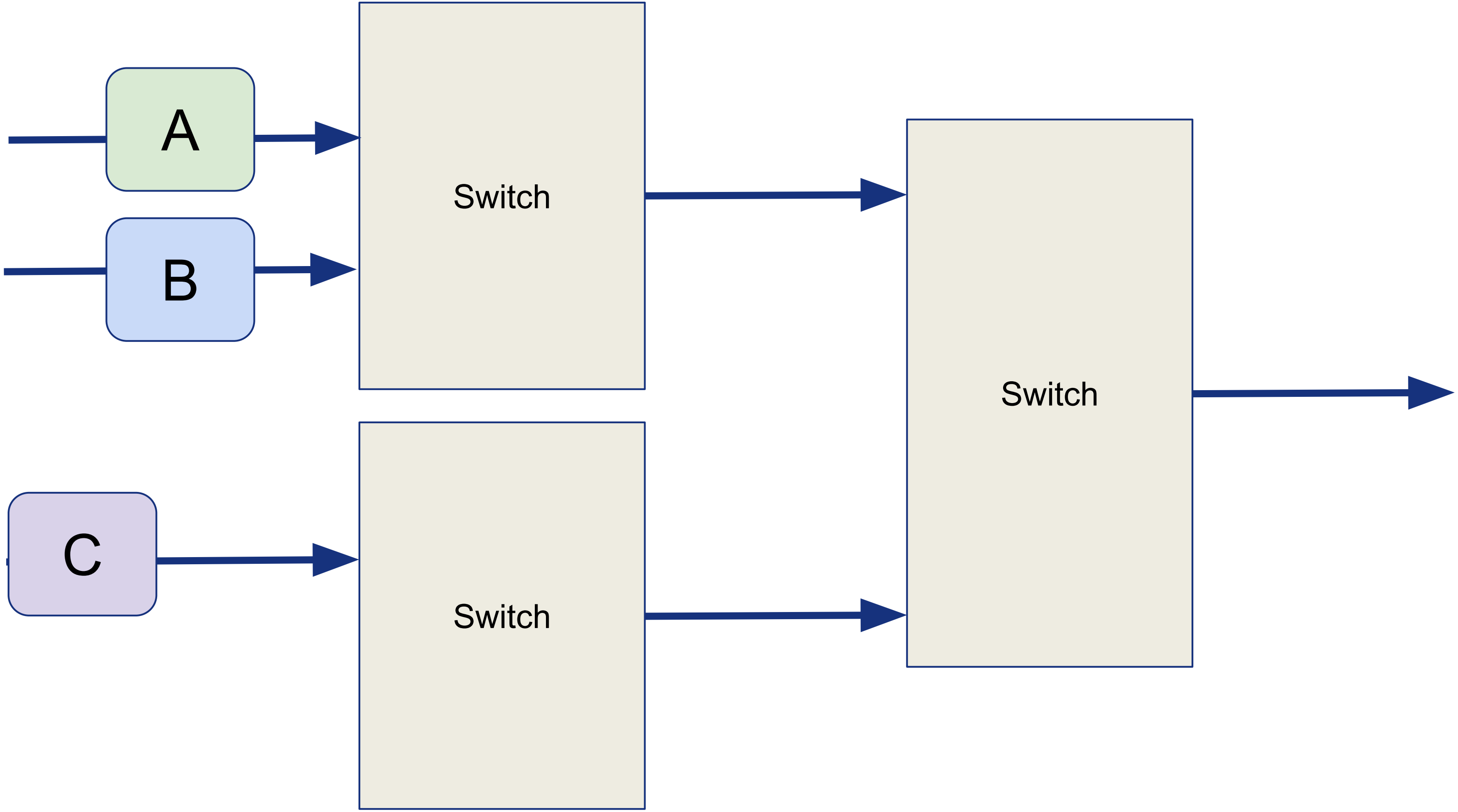

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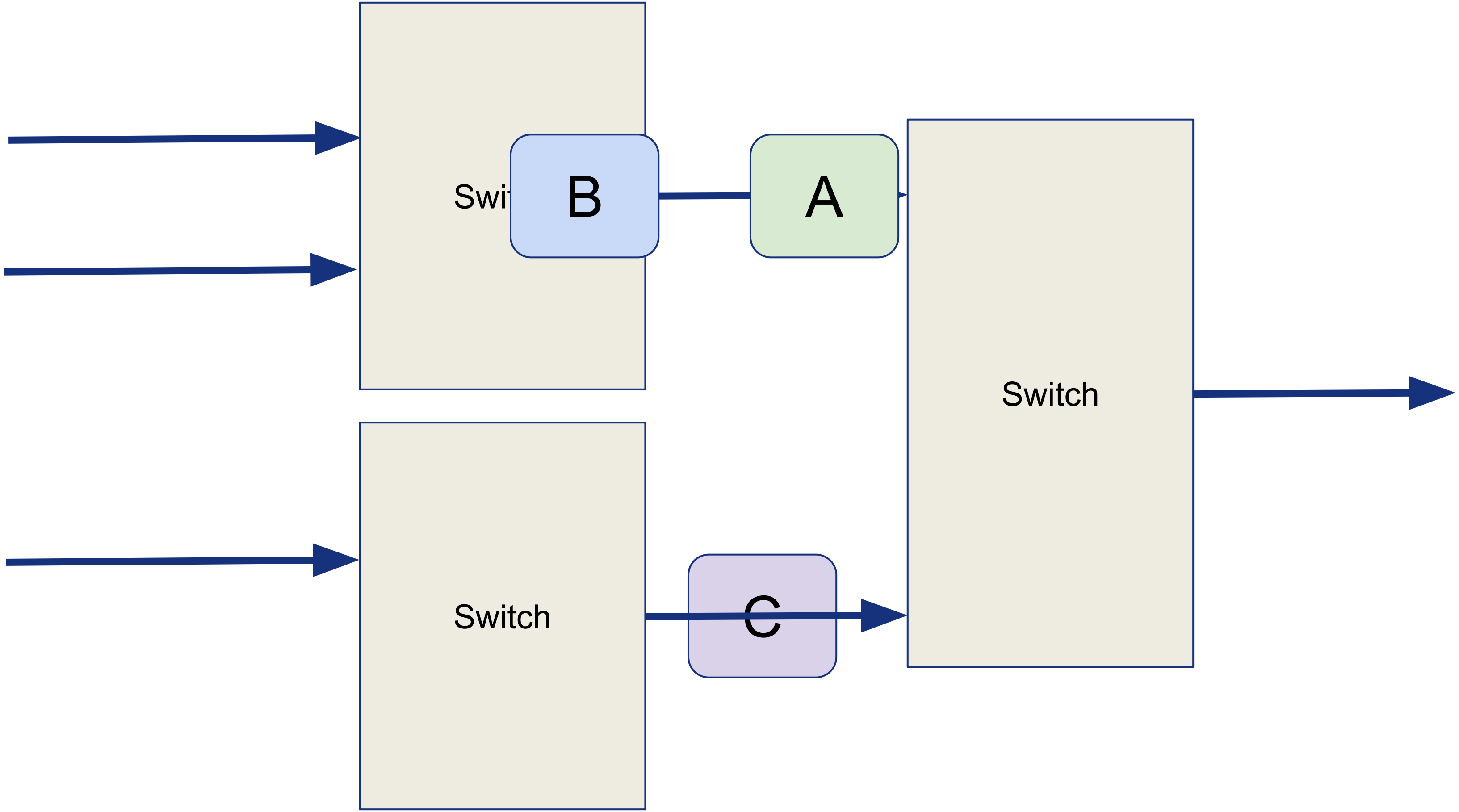

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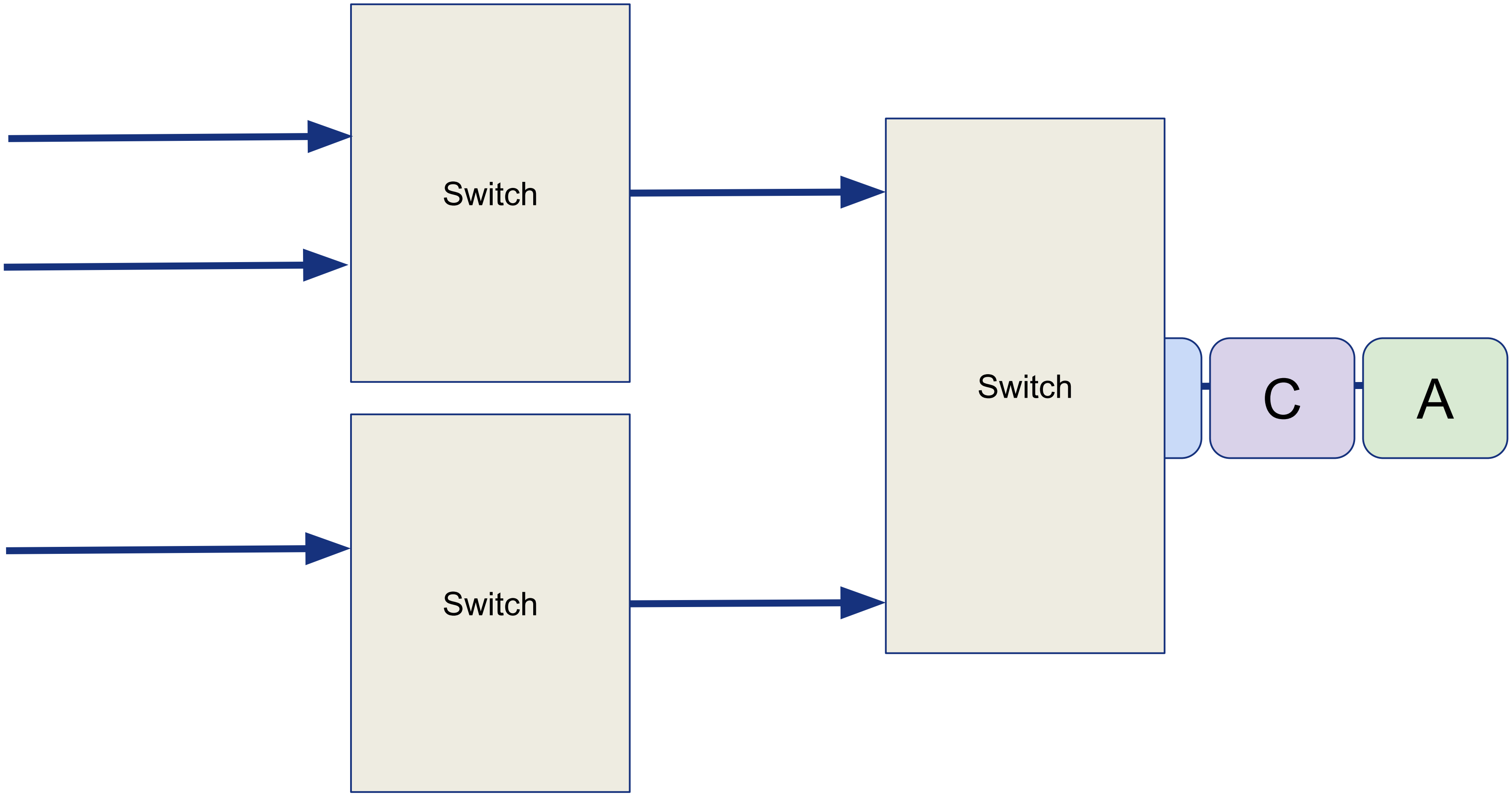

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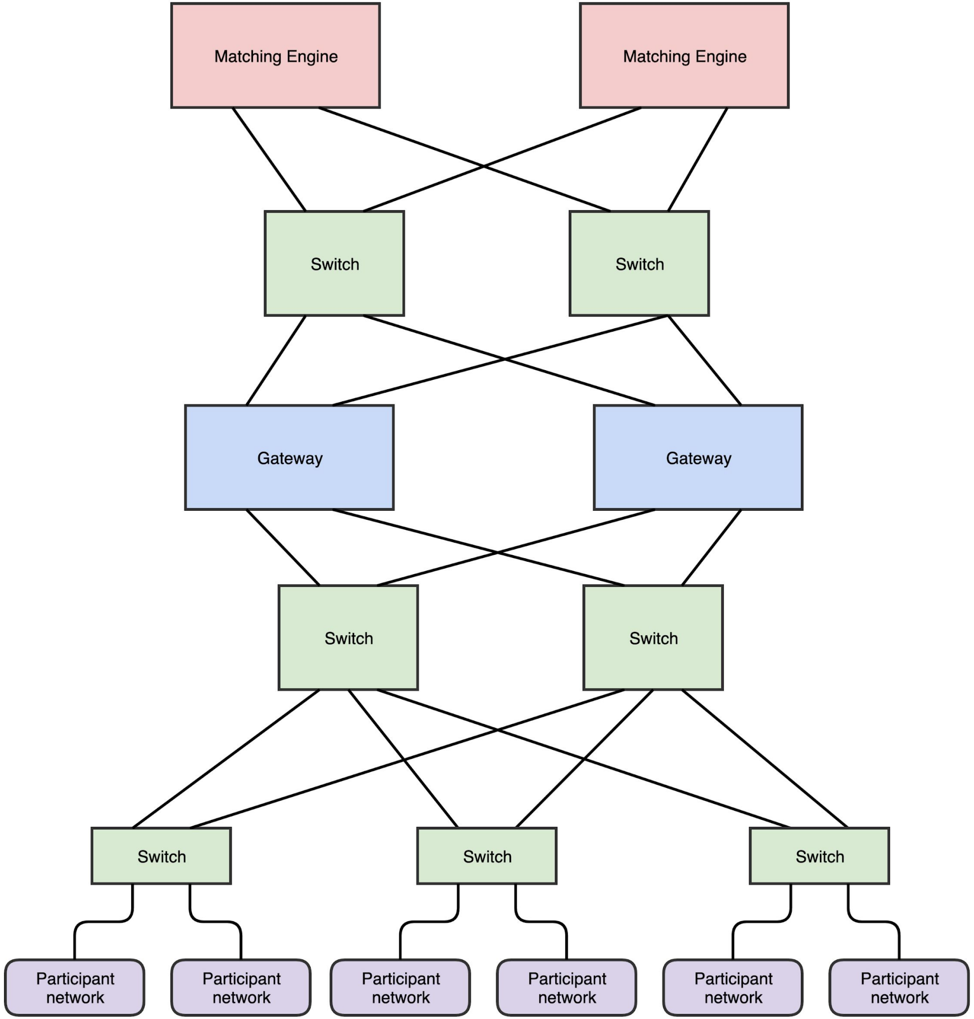
Typical issues

- Equal-length fibres that aren't so equal.
  - Fibre-lengths inside the venue



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Getting to the nub of it…

- Few venues really understand their imperfections.
- As always, there’s a trade-off between latency/determinism and bandwidth

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Some things we’ve talked about...

- *We want our response time to be better*
  - Latency at exchanges is usually pursued to gain determinism.
- *The HFTs are going to hate you for this*
  - Most HFT firms that I talk to would be happier to spend their time, energy and money on something more productive.
- *We like the randomness… It helps stop the HFTs.*
  - If you want randomness, get to perfection, and add *true* randomness, not a predictable systematic error.

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Latency vs. determinism

- Latency optimisation is about reducing some measure of delay
  - minimum, median, average, worst case?
- Determinism is about consistency
  - Consistency is required for fairness -- the exchange should do what it says on the tin.
- Bandwidth is about volume
  - How many orders per second can we handle?

For fairness, venues need to optimise for determinism at the participant interface.

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Some other questions...

- What’s the event that matters?
  - First bit of the first or last network packet containing the order?
    - Out of order TCP segments, IP fragments?
  - The last bit of the order network message?

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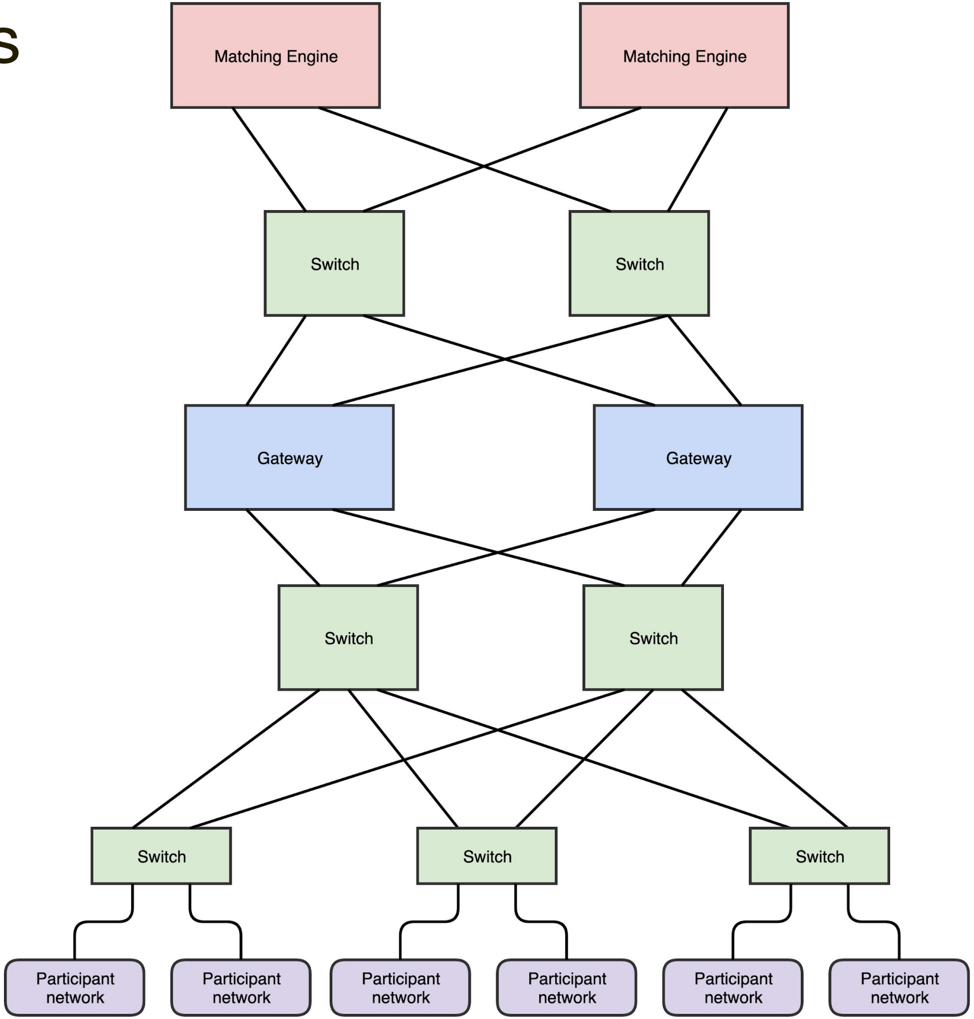
Typical venue optimisations

Do:

- Co-location, matched fibres
- Low-latency switches
- Single threaded software
- Single gateway architecture
- Single data rate networks (10G)
- Cut through switching
- Specialist network stacks (e.g. Solarflare's Onload, WODA)
- FPGA implementations

Don't:

- Use VMs, cloud
- Use new high bandwidth links



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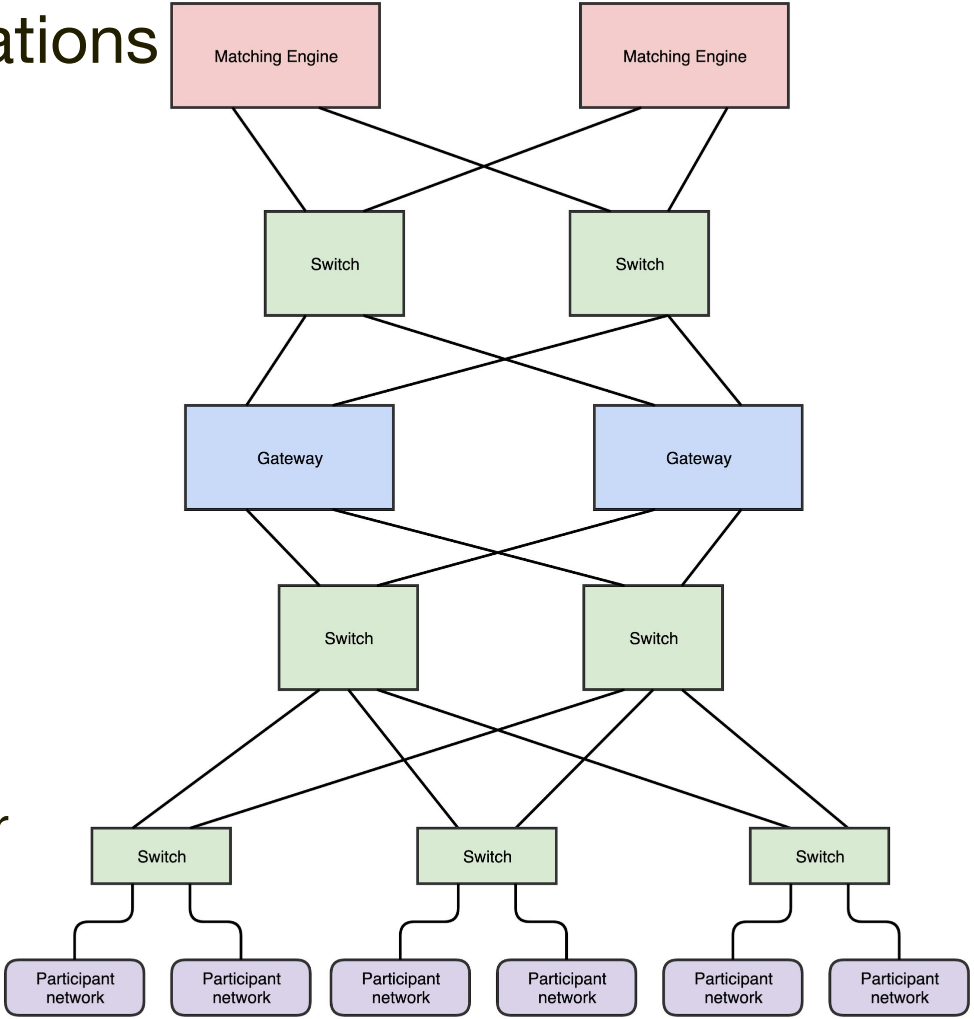
Typical participant optimisations

- Connect to every switch and use the earliest copy of each message.
- Model switch congestion and queueing to avoid adverse selection.
- Model/monitor the gateways.
- Game the network stack to reduce serialisation delay
- Start transmitting early to “reserve” the line -- pad the front of the packet until you know your order info.



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What can we do?

- Step 1: Measure what needs to be measured, as accurately as it needs to be measured.
  - Understanding the symptoms will indicate the problems.

> "To know thyself is the beginning of wisdom."
>
> — Socrates

How to measure event timing in an exchange?

- Software timestamps
- Network packet capture
- In the future:
  - virtual network interface?
  - In the NIC?

- Disclaimer (sort of): we have a product that does this.

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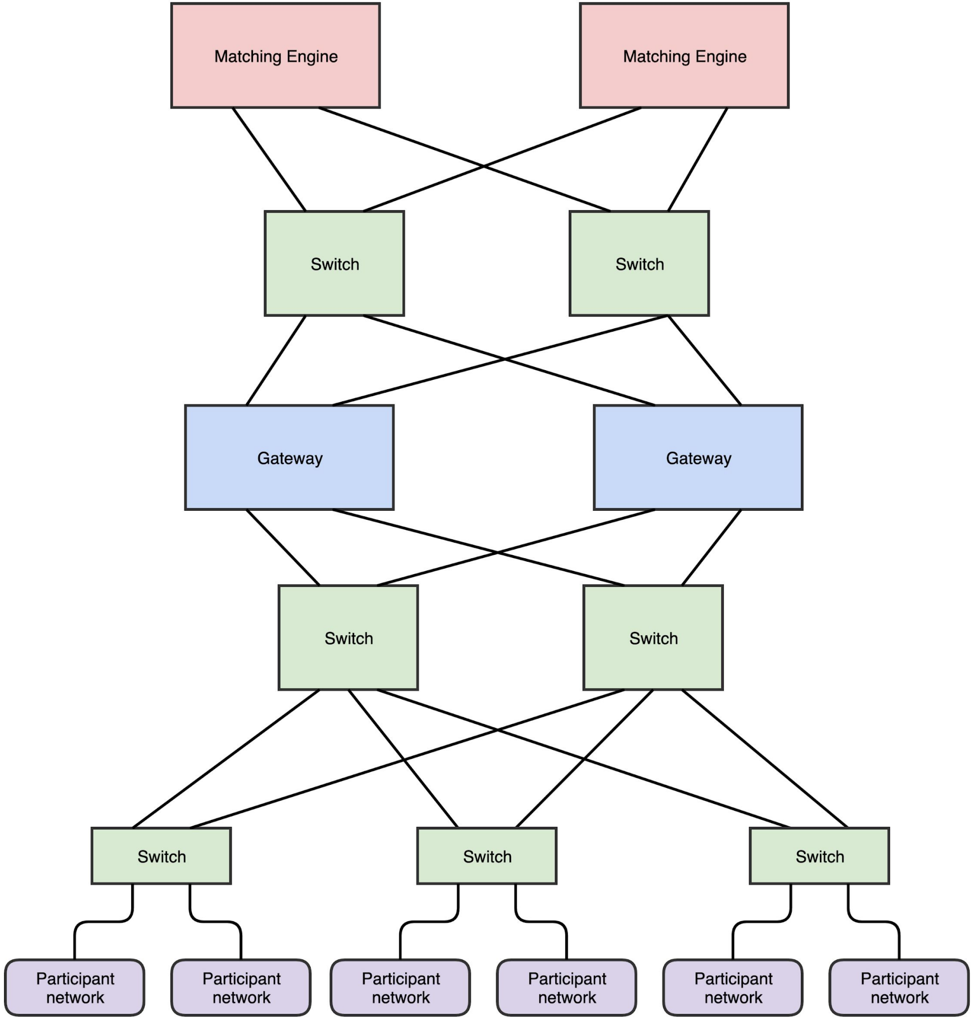
Where to measure?



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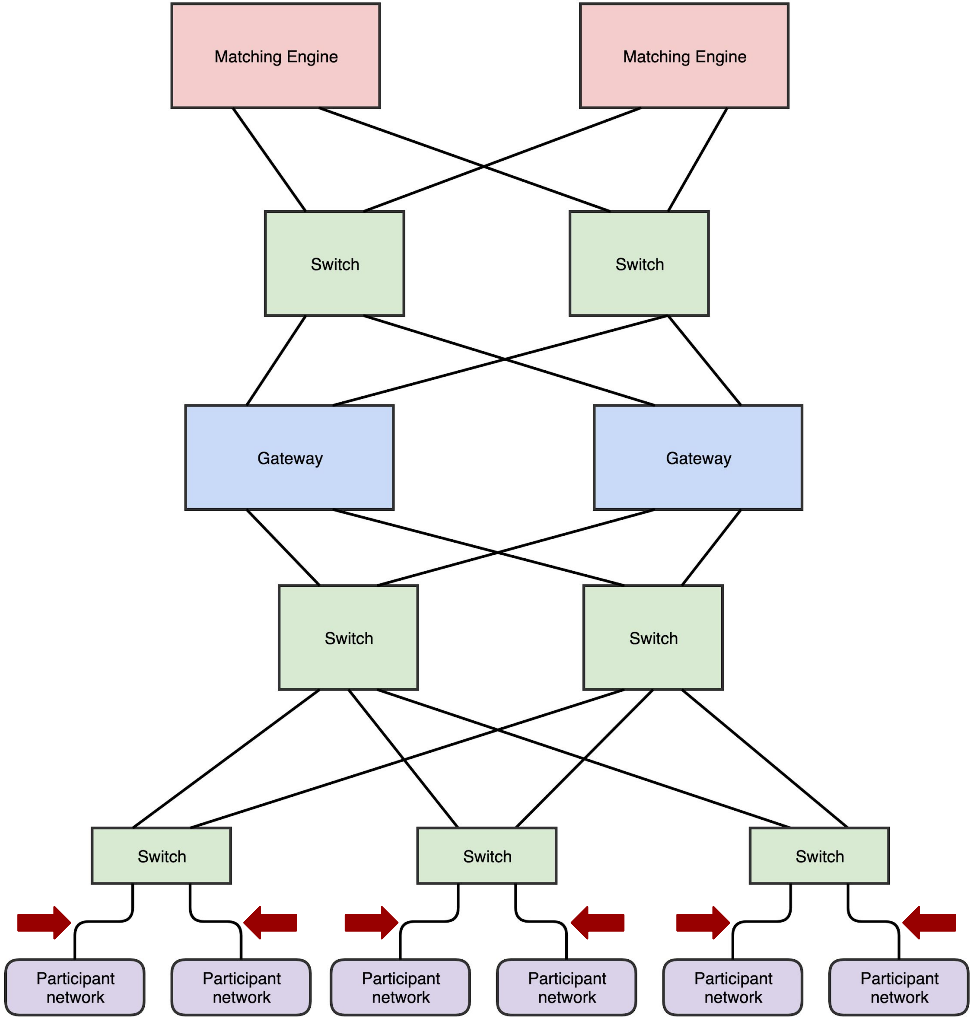
Where to measure?

- Measuring means measuring at the interface that matters.



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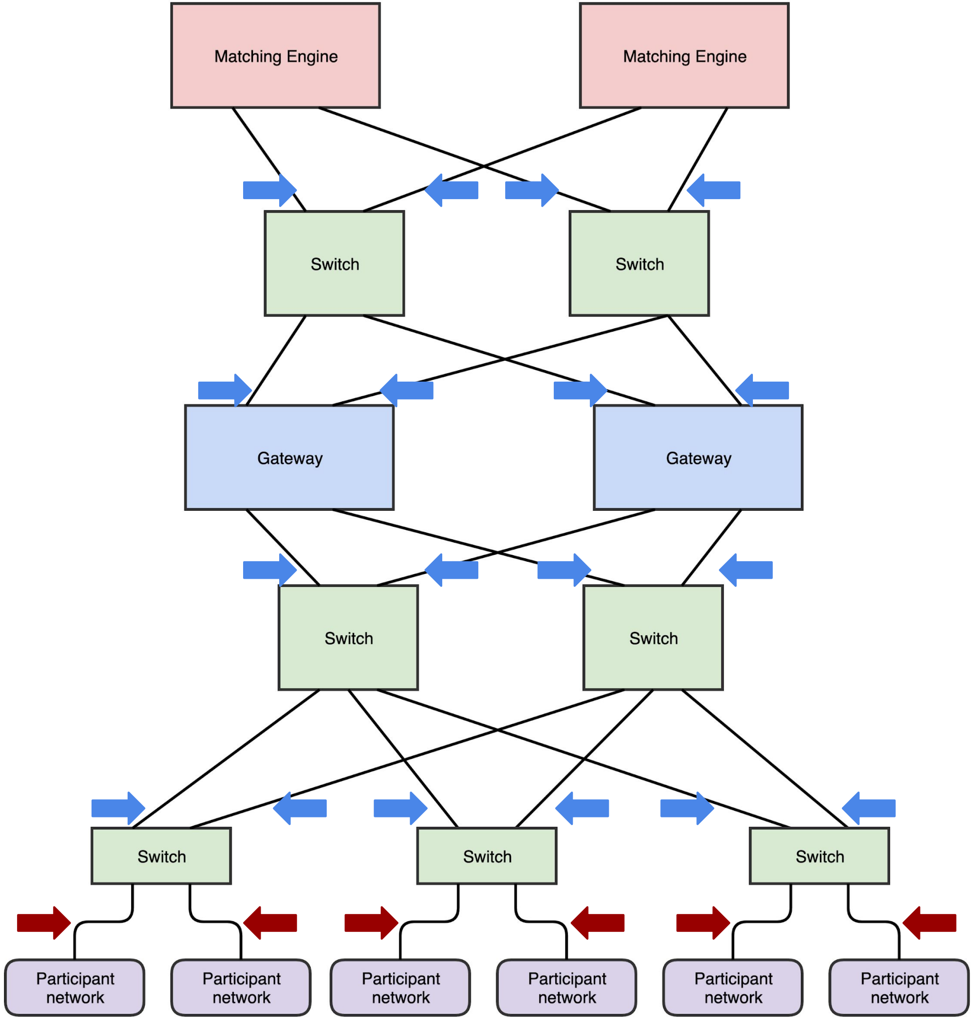
Where to measure?

- Measuring means measuring at the interface that matters.

- But there are lots of places that useful to know about.



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But how?

- Technology to the rescue. This is a **solved** problem.

- Software
  - Clocks can be synchronised to substantially sub-micro errors.
  - e.g. PTP, Ticktock Huygens, FSM Timekeeper

- Network capture:
  - We can measure across thousands of network links to sub-nano resolution. (Not STAC benchmark). e.g. Arista.

- STAC-TS is a great tool to measure this area.

NOT STAC BENCHMARK

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But how?

- Deutsche Boerse have instrumented to better than 10 ns.
  - Seven Solutions + Arista
  - Very wide ranging instrumentation
  - Great example of transparency!
    - https://www.eurexchange.com/resource/blob/48918/09570713f62b7719635742e52d525d87/data/presentation_insights-into-trading-system-dynamics_en.pdf

NOT STAC BENCHMARK

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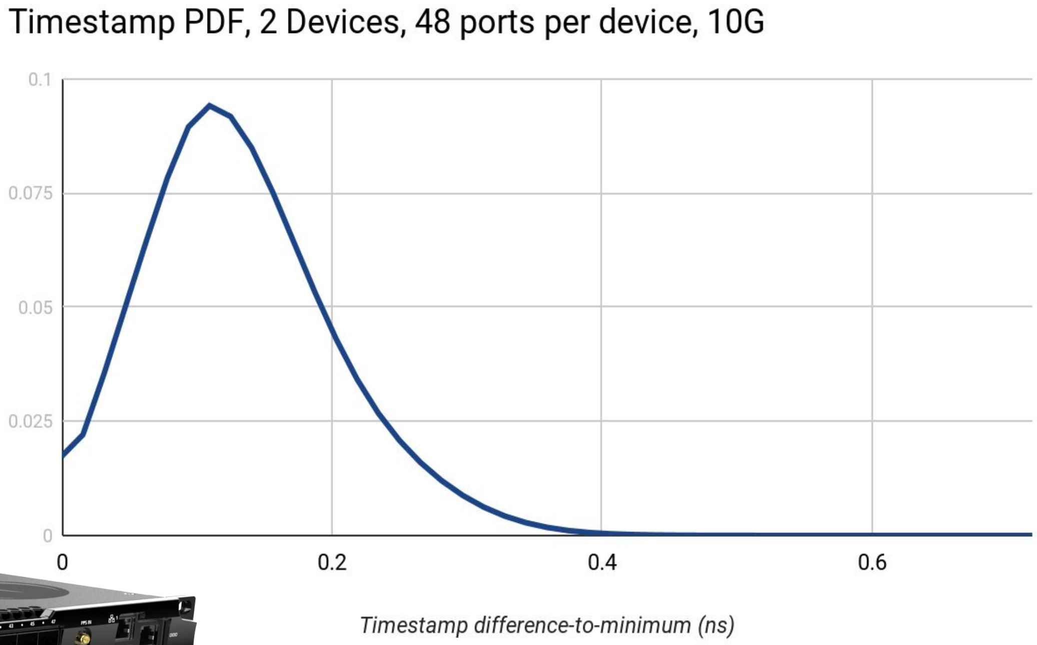
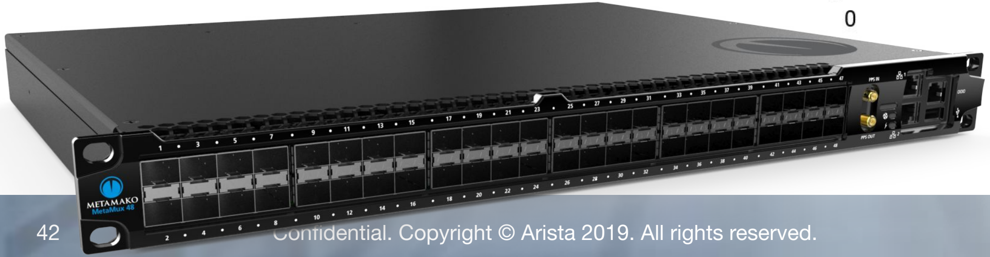
Some not-STAC benchmarks...

- Two devices, sync'd via PPS.
- Replicate a packet to all 96 ports.
- For each packet, measure the difference to the min timestamp.

- **Max difference: 0.719 ns**

Arista 7130L - Two switches, PPS sync





NOT STAC BENCHMARK

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What can we do?

- Step 2: Solve what can be solved.

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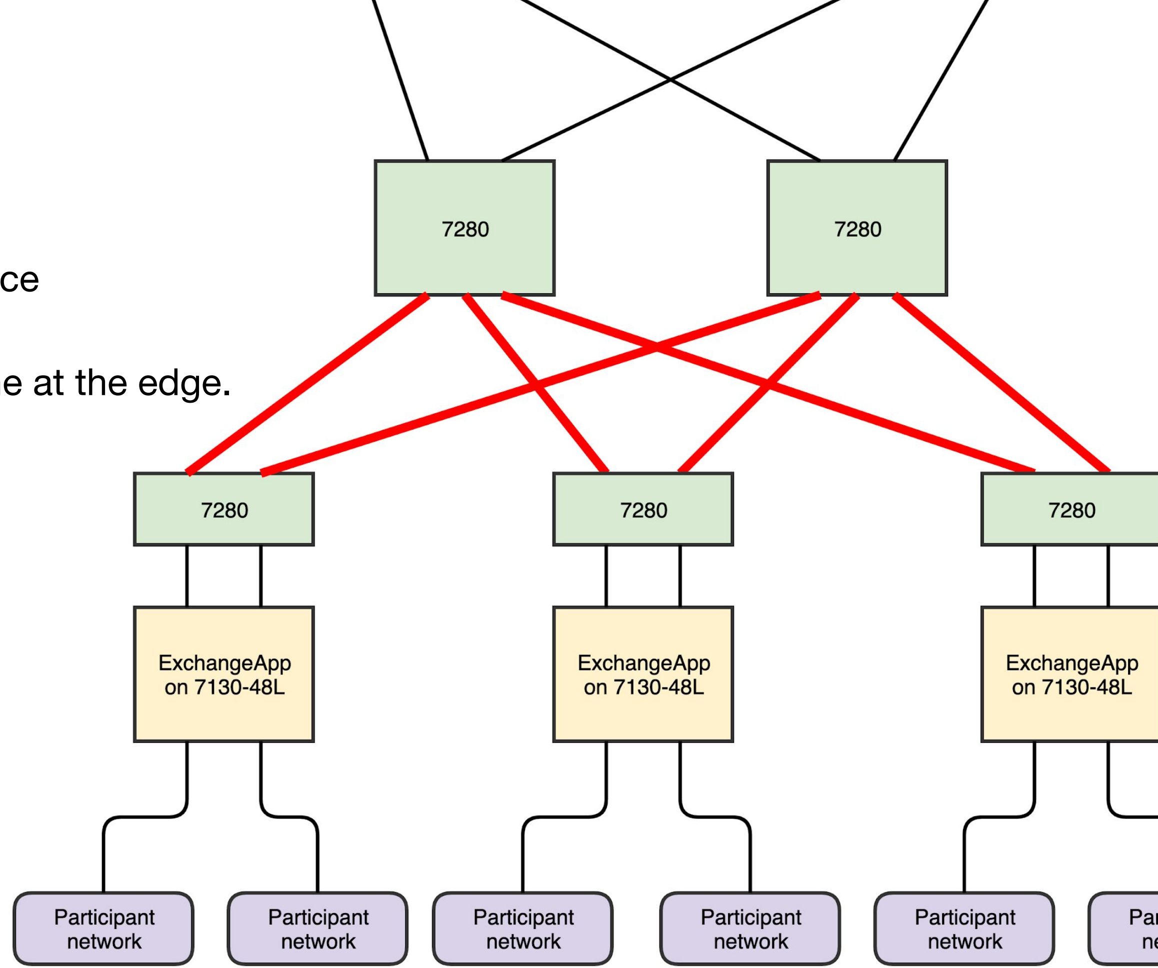
What can we do?

- Step 3: Change the paradigm.
  - Make time as explicit as price
  - Measure event timing
- Arista’s solution: timestamp in-line at the edge.



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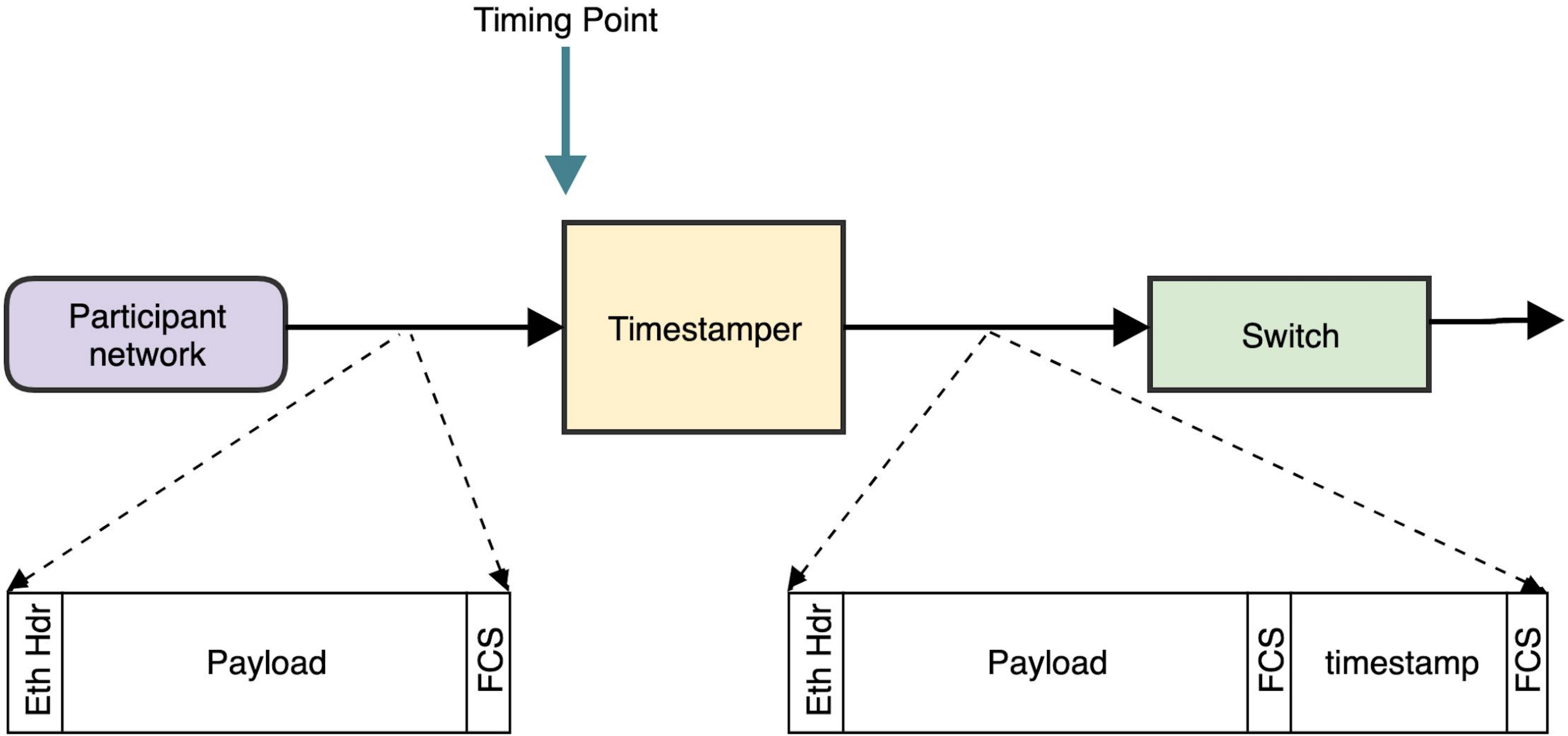
Timestamping at the edge...



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ExchangeApp

- It turns out that switches only modify packet headers, so trailers make it to the gateway, even with an L3+ network.

- Venue operators now don’t have to worry about latency. This is nice!
  - Reduce contention using store/forward, fat core pipes.
  - Reduce loss using deep buffer switches, dynamic routing.
  - Use multiple gateways, switches, etc.

- The next challenge is how to deliver responses. Watch this space.

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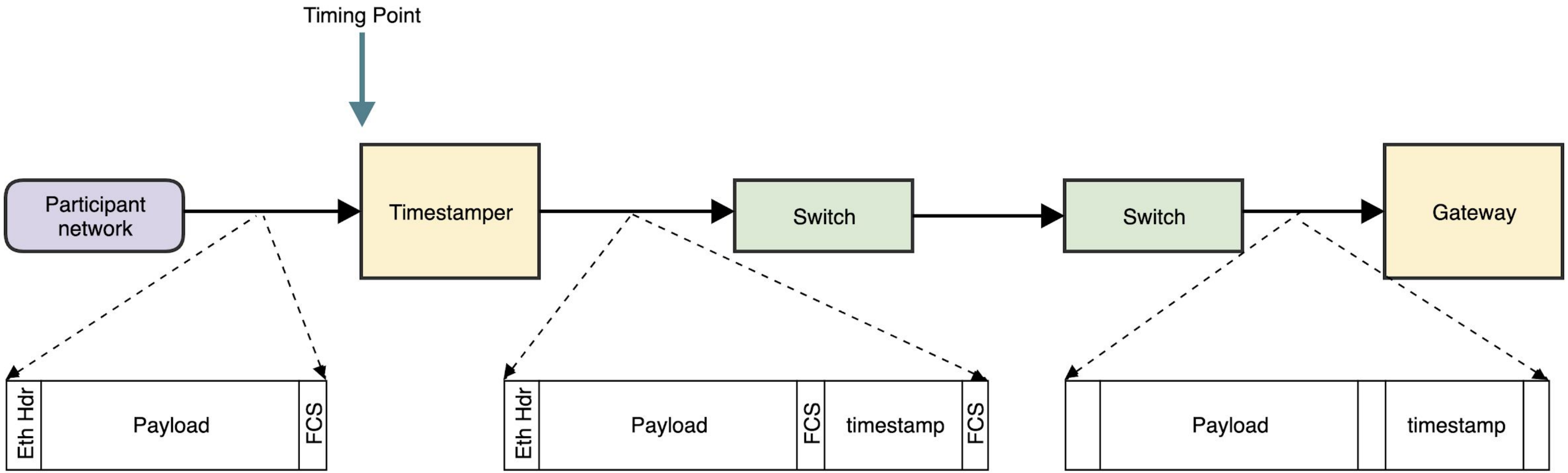
Timestamping at the edge...



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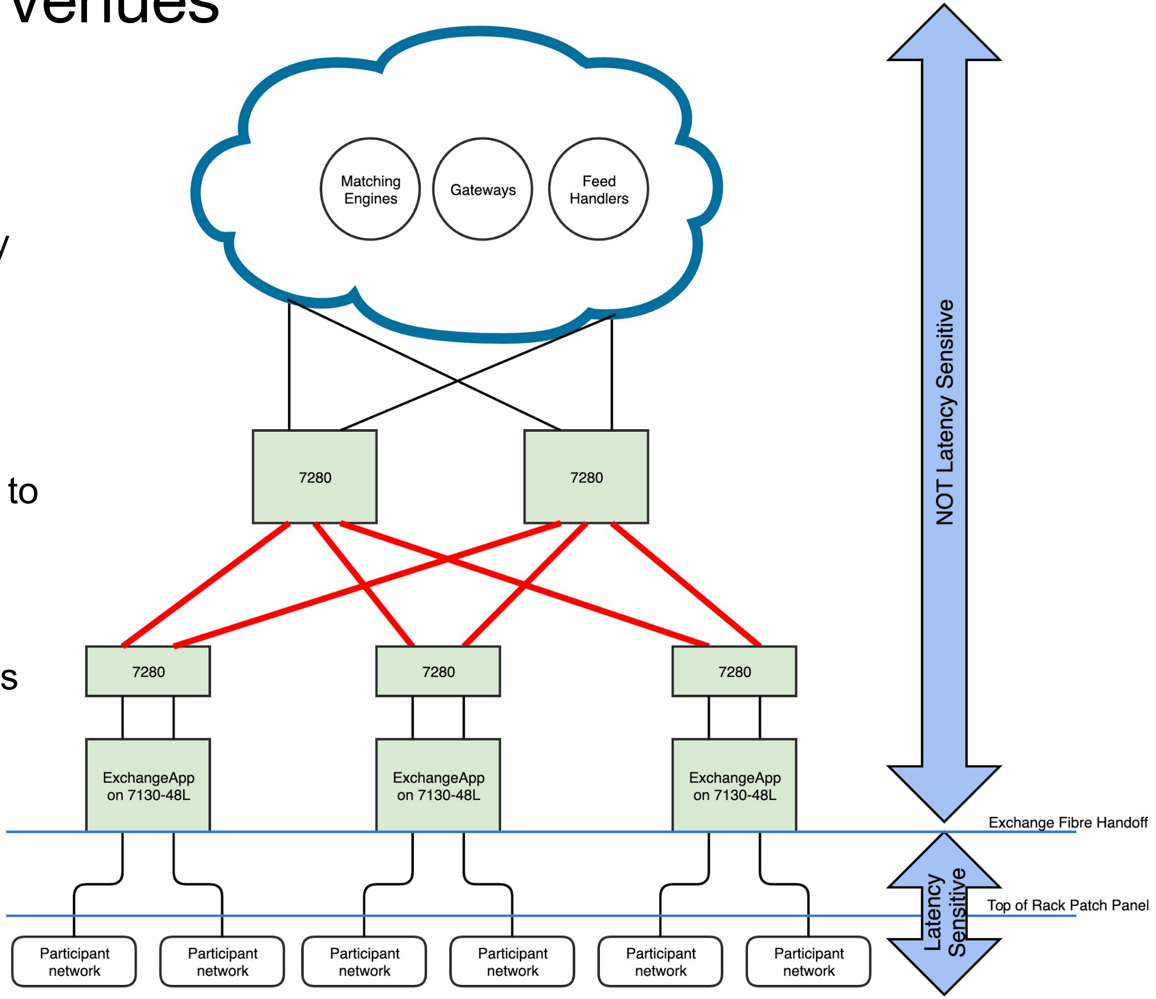
A better way to build venues

- Enabled by reliable accuracy.
- Timestamp at the edge.
- Stop worrying about time/latency in the venue implementation.
- Reason about time in software instead.
- Use jittery-but-better technology to implement your venue:
  - Deep buffers
  - Store-and-forward switches
  - VMs/Containers
  - Cloud
  - Garbage collection



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Implications

- Venue operators don't have to be quite so paranoid about latency, because we already have the determinism.
- That means we can build a better venue -- focus on avoiding queuing and improving reliability by building the network *right*.
- Software can be implemented using best practices, without restriction.
- Fibre matching can be achieved using fixed timestamp offsets.
- Will sub-nano determinism result in a new arms race?
    - Re-ordering based on time-of-arrival is only one policy.
- I can't currently work out how to game this without a good workaround.
    - Let me know if you can.

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For participants

- Will this result in an accuracy arms race?
  - Winner-takes-all is probably not in anyone’s interest.
  - Probably not -- executing in order-of-timestamp enables randomisation, discrete auctions, or other policies.

- Could accurate markets mean the end of co-location?
  - Probably not.

- Are there better policies that we could implement?
  - Almost certainly.

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The markets aren’t perfect. And technology can help.

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