Pitfalls of data-driven networking: A case study of latent causal confounders in video streaming

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Say you want design a video streaming system...
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What If...

- A different algorithm had been used?

- Viewers started playing 4K videos? Would they experience buffering?
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Counterfactual questions
What this talk is about

- What are the challenges involved in answering counterfactual questions for networked systems?
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- A study of these challenges in the context of video streaming algorithms
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- A study of these challenges in the context of video streaming algorithms

- Limitations of current methods, and a preliminary approach to overcome these challenges
Background: Video Streaming (ABR)
A video is encoded into multiple qualities (bitrates)
Background: Video Streaming (ABR)

Each bitrate is split into chunks
Background: Video Streaming (ABR)

- Video Client
- Network Conditions vs. Time
- Video Server
- Request \( n \)th chunk at bitrate \( r \)
Counterfactuals for video streaming

- What if ABR 2 had been used instead of ABR 1?
Counterfactuals for video streaming

- What if ABR 2 had been used instead of ABR 1?

- Alternatively, what if a different sequence of bitrates had been downloaded?
Counterfactuals for video streaming

ABR 1 → Deployment → Traces → Performance Evaluation
Counterfactuals for video streaming

ABR 1 -> Deployment -> Traces -> Performance Evaluation

ABR 2
Counterfactuals for video streaming

ABR 1 → Deployment → Traces → Performance Evaluation

ABR 2 → Offline trace based execution → Performance Evaluation
Evaluating video streaming systems using traces

Diagram:
- ABR 1 → Deployment → Traces → Performance Evaluation

- (t, s, d)
  - (0, 1Mb, 1s)
  - (1, 2Mb, 1s)
  - (2, 1Mb, 1s)

Definitions:
- t: download start time of chunk
- s: size of chunk
- d: download time
Evaluating video streaming systems using traces

ABR 1 → Deployment → Traces → Performance Evaluation

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...

\[ t: \text{download start time of chunk} \]
\[ s: \text{size of chunk} \]
\[ d: \text{download time} \]
What can go wrong with using traces?
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- Traces generated by adaptive algorithms can affect trace driven evaluation!
What can go wrong with using traces?
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- **ABR-Probe** probes bandwidth before downloading a chunk
- Chooses bitrate to match the probed bandwidth
What can go wrong with using traces?

- (t, s, d)
- (0, 1Mb, 1s)
- (3.2, 2Mb, 1s)
- (4.6, 1Mb, 1s)
What can go wrong with using traces?

(t, s, d)
(0, 1Mb, 1s)
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Bandwidth (B)
(hidden, true)

Object Size (S) → Download Time (D)
The issue of confounders

Confounders induce dependencies in the data that are often unaccounted for.
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This can affect the accuracy of trace based execution.
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This can affect the accuracy of trace based execution.
Existing approaches to deal with confounders

- Randomized Controlled Trials (RCTs)
  - Choose the bitrates at random so that the bandwidth doesn’t affect it
  - RCTs don’t work here - Trace collection is impractical, other data dependencies
Existing approaches to deal with confounders

- **Randomized Controlled Trials (RCTs)**
  - Choose the bitrates at random so that the bandwidth doesn’t affect it
  - *RCTs don’t work here* - Trace collection is impractical, other data dependencies

- **Observational Studies (Matching on confounders)**
  - Find data in the original trace that matches what you’d like to estimate in your new system, and use that as a measurement
  - Do not account for latent confounders [1][2]

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What if you could account for latent confounders?

- We conducted a case study on the simplest scenario that illustrated the problem.
Illustrative Case Study

- Create trace by downloading a video using ABR-Probe
- Use trace to evaluate performance of second bitrate sequence
Illustrative Case Study

- Create trace by downloading a video using ABR-Probe
- Use trace to evaluate performance of second bitrate sequence
- Assumptions:
  - $\theta$: session phase, hidden
  - $\psi$: chunk start phase, hidden
  - $B_h, B_l, T$ are known
Our Approach

- Construct causal graph for trace production process
- Infer hidden confounders from the data
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- Construct causal graph for trace production process

- Infer hidden confounders from the data

- Use trace with inferred confounders to evaluate performance of second sequence
Our Approach

- **Key Idea:**
  - Infer the chunk phase explicitly from the data

- **Use Maximum A Posteriori estimation**
  - All of the details in the paper
Evaluation

- **Trace Production**: ABR, Randomized bitrates
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  - Calculate download times of new sequence of bitrates using only the trace as input, with different methods
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- **Trace based evaluation**
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  - **Evaluation metric**: Error in download time calculation from trace vs ground truth deployment
  - How accurate was it in answering the counterfactual compared with ground truth?
Evaluation

- Trace based evaluation methods
  - Direct Emulation - Use observed throughput from trace as bandwidth model
  - Match - No Latent - Match on measured features only (bitrate)
  - Match - Latent - Our method: match on bitrate and inferred chunk phase
Takeaways

Trace Production: ABR-Probe

![Graph showing CDF (Frac. of test video sessions) vs. Download Time MAPE [%] with different lines for Match-NoLatent, Match-Latent, and DirEmul, indicating which one is better.](image)
Takeaways

Trace Production: ABR-Probe

- Direct Emulation based on the observed throughputs is not accurate for evaluation - median error ~18%
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Trace Production: ABR-Probe

- Direct Emulation based on the observed throughputs is not accurate for evaluation - median error ~18%
- Performing matching without accounting for confounders can be even worse
- Matching on latent confounders is the most accurate
Using RCTs

Trace Production: Randomized bitrates

- Similar results
- Match-Latent is optimal
Conclusions and Future Directions

- First step towards answering counterfactual questions with video streaming systems
  - Key challenge: True bandwidth process is not available - latent confounders
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  - Key challenge: True bandwidth process is not available - latent confounders

- Preliminary approach to deal with latent confounders
  - RCTs and matching techniques insufficient without considering latent confounders
Conclusions and Future Directions

● First step towards answering counterfactual questions with video streaming systems
  ○ Key challenge: True bandwidth process is not available - latent confounders

● Preliminary approach to deal with latent confounders
  ○ RCTs and matching techniques insufficient without considering latent confounders

● Challenges and Future Directions:
  ○ Generalization towards richer bandwidth processes, what this means for more complex scenarios