



Statistics By Default

Lecture 1: A/B Testing

Notes and slides can be found here:
<https://github.com/drewrl3v/StatsByDefault>

Andrew Lizarraga

What this course **IS NOT**:

- This is not tutoring!

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- I won't have time to go into every detail.

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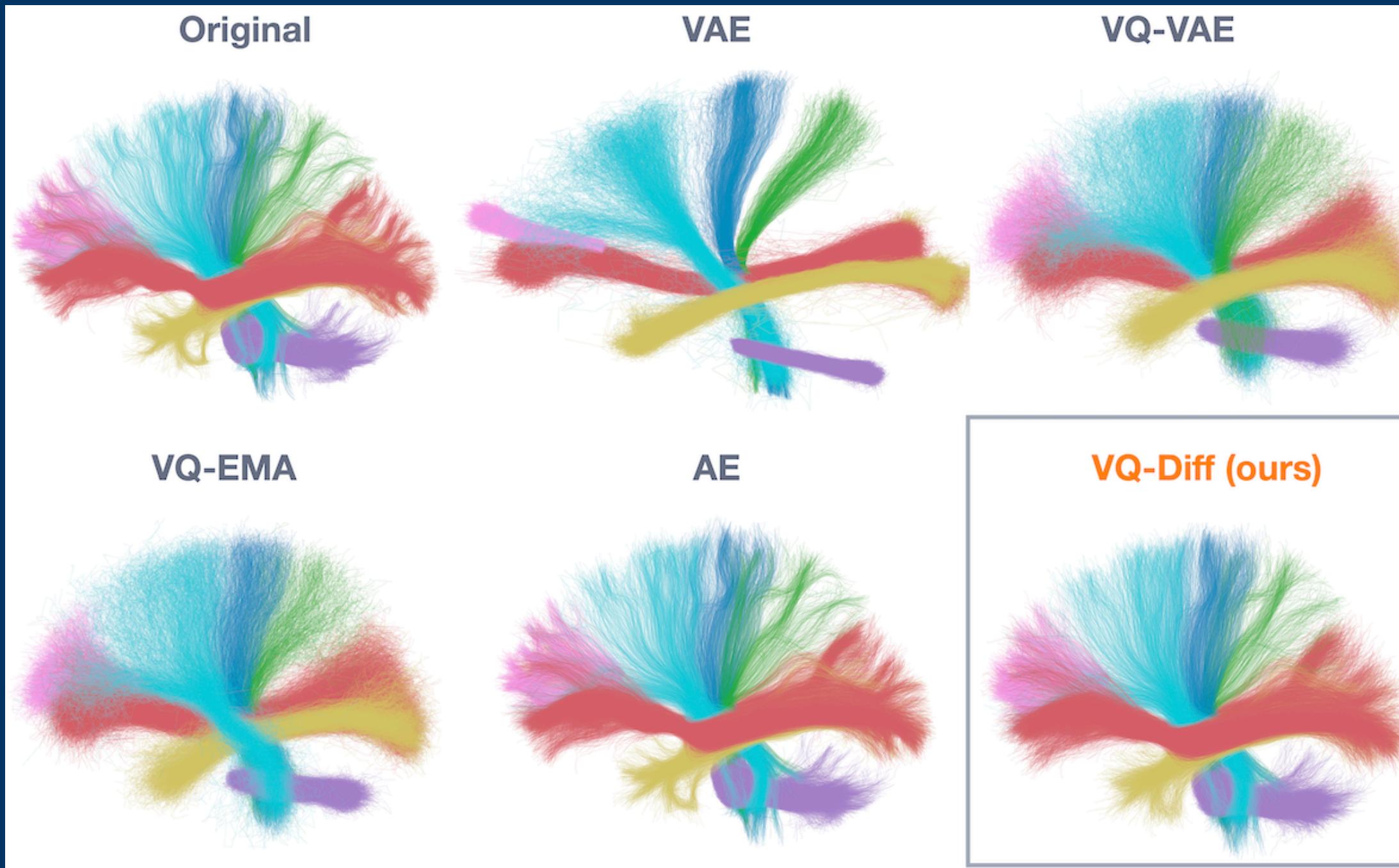
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- However you get as much as you put in.

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- However you get as much as you put in.
- Be sure to help your peers!

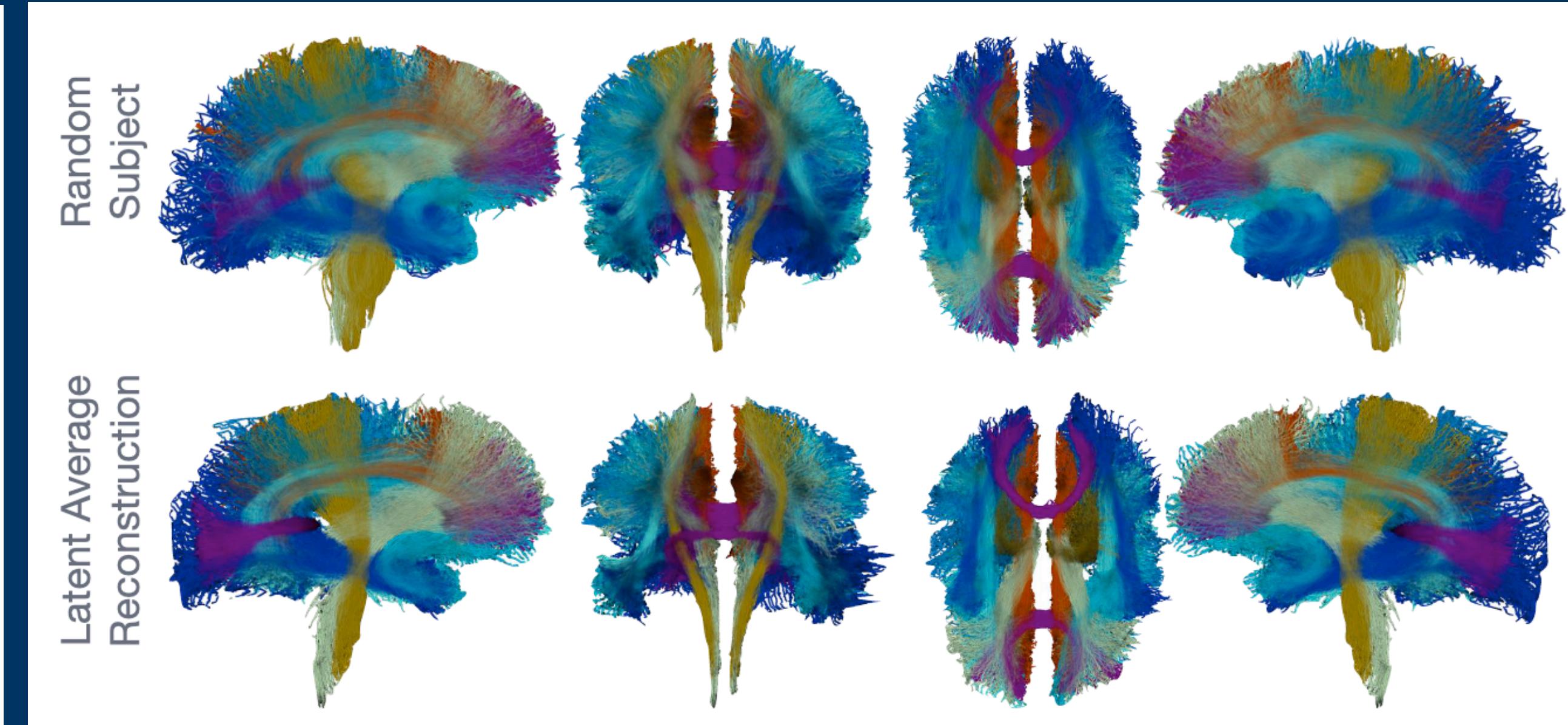
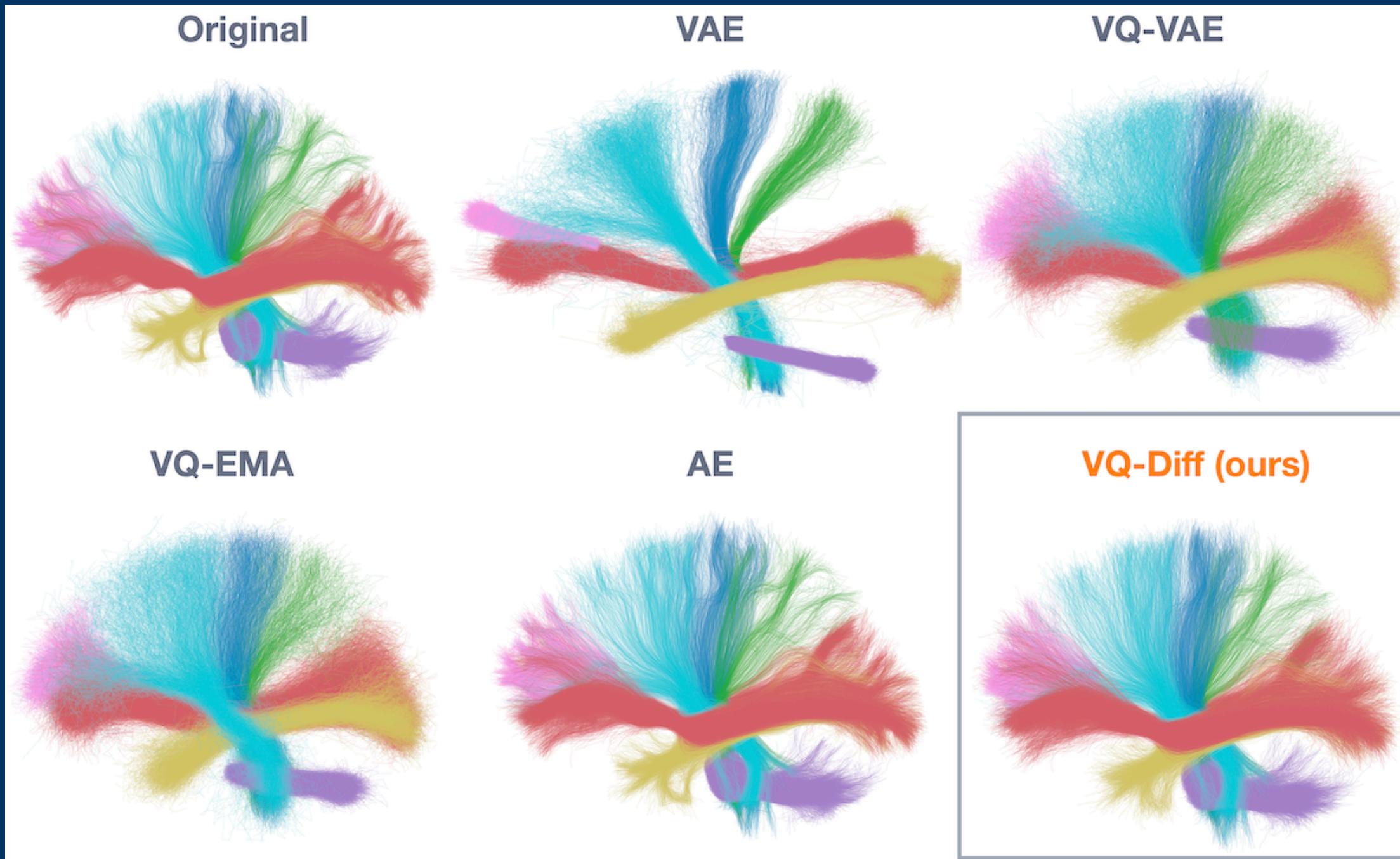
Quick About Me

- Research - AI4Science / Generative Models / Latent Modeling



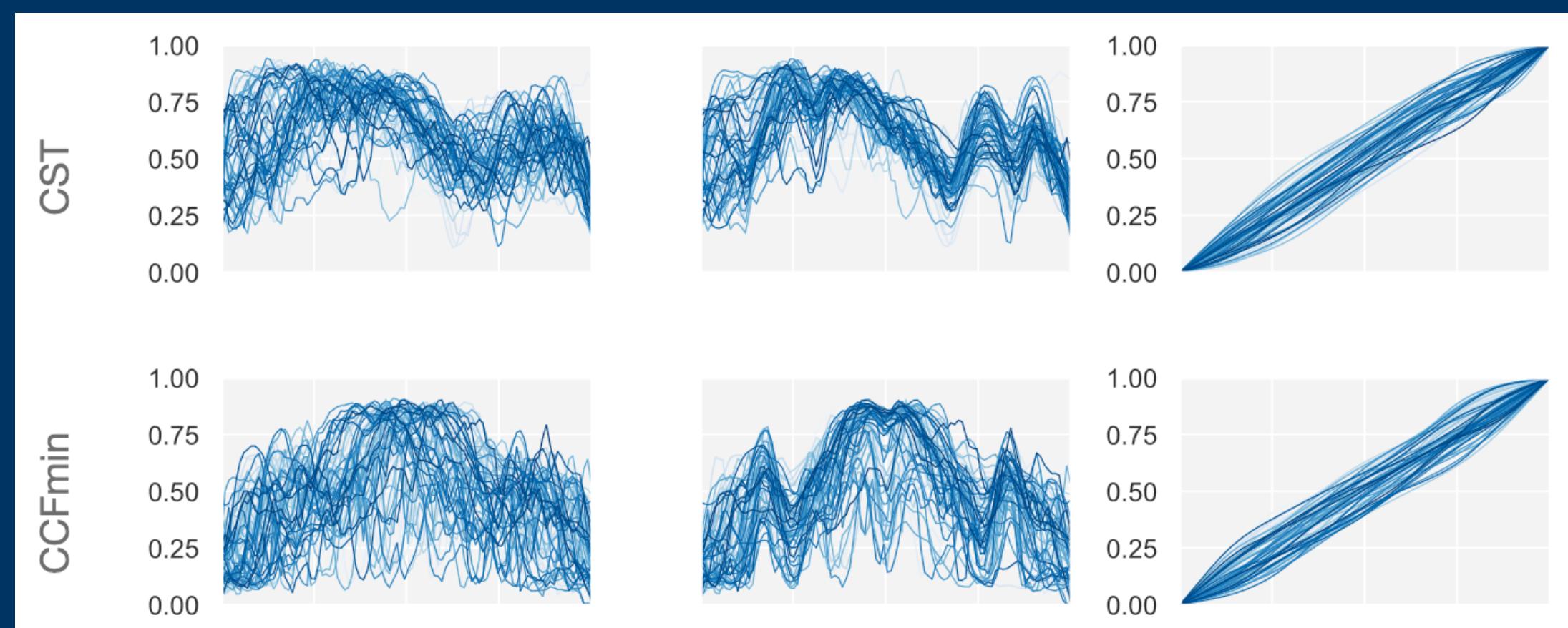
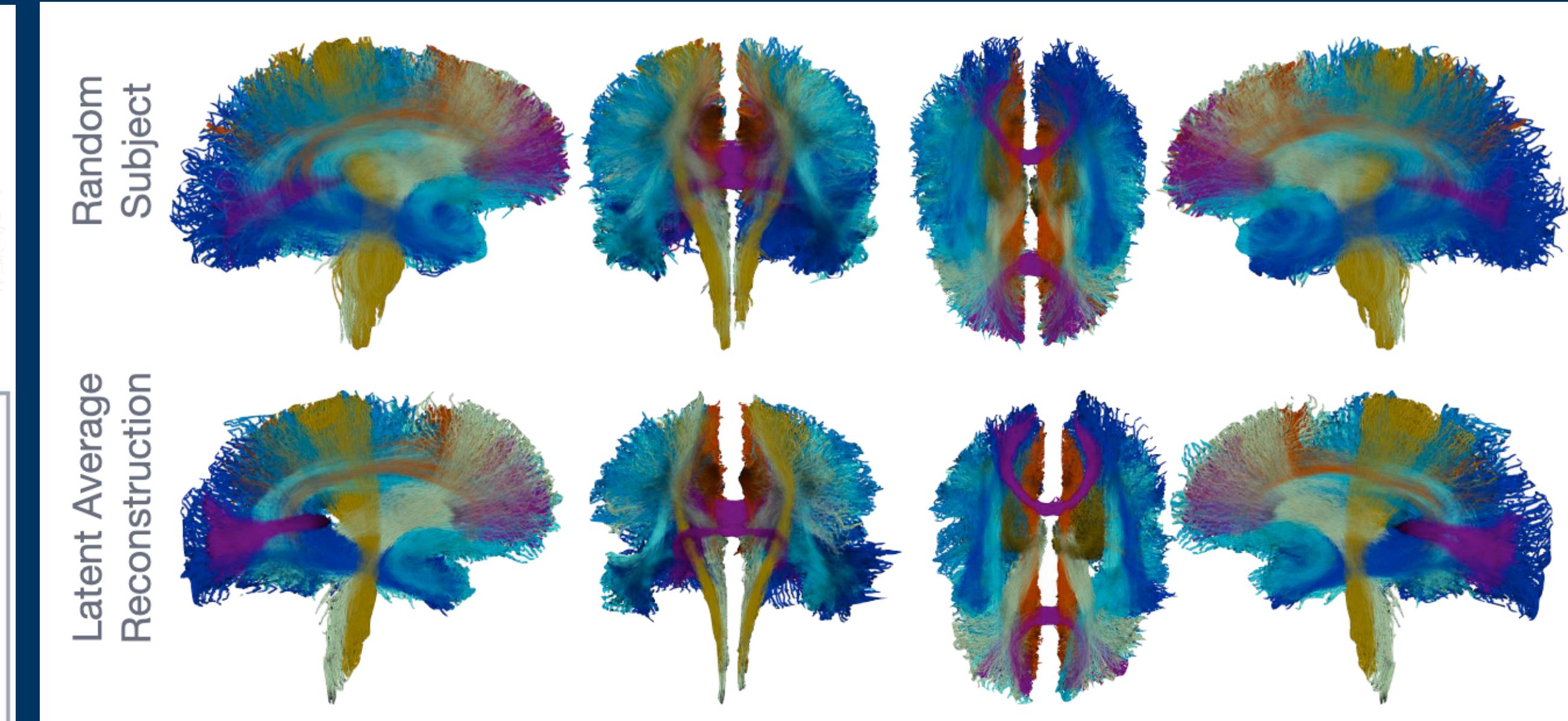
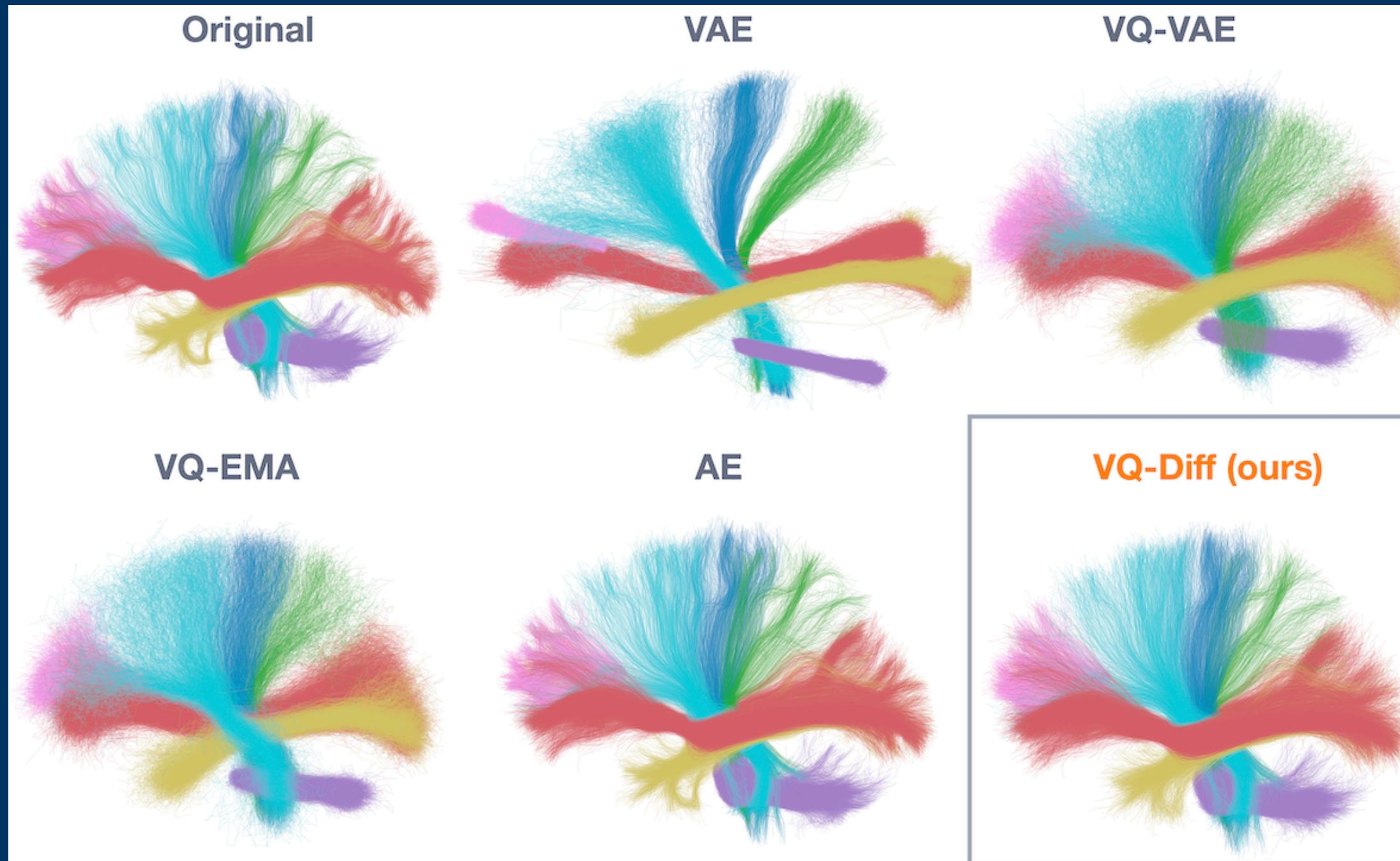
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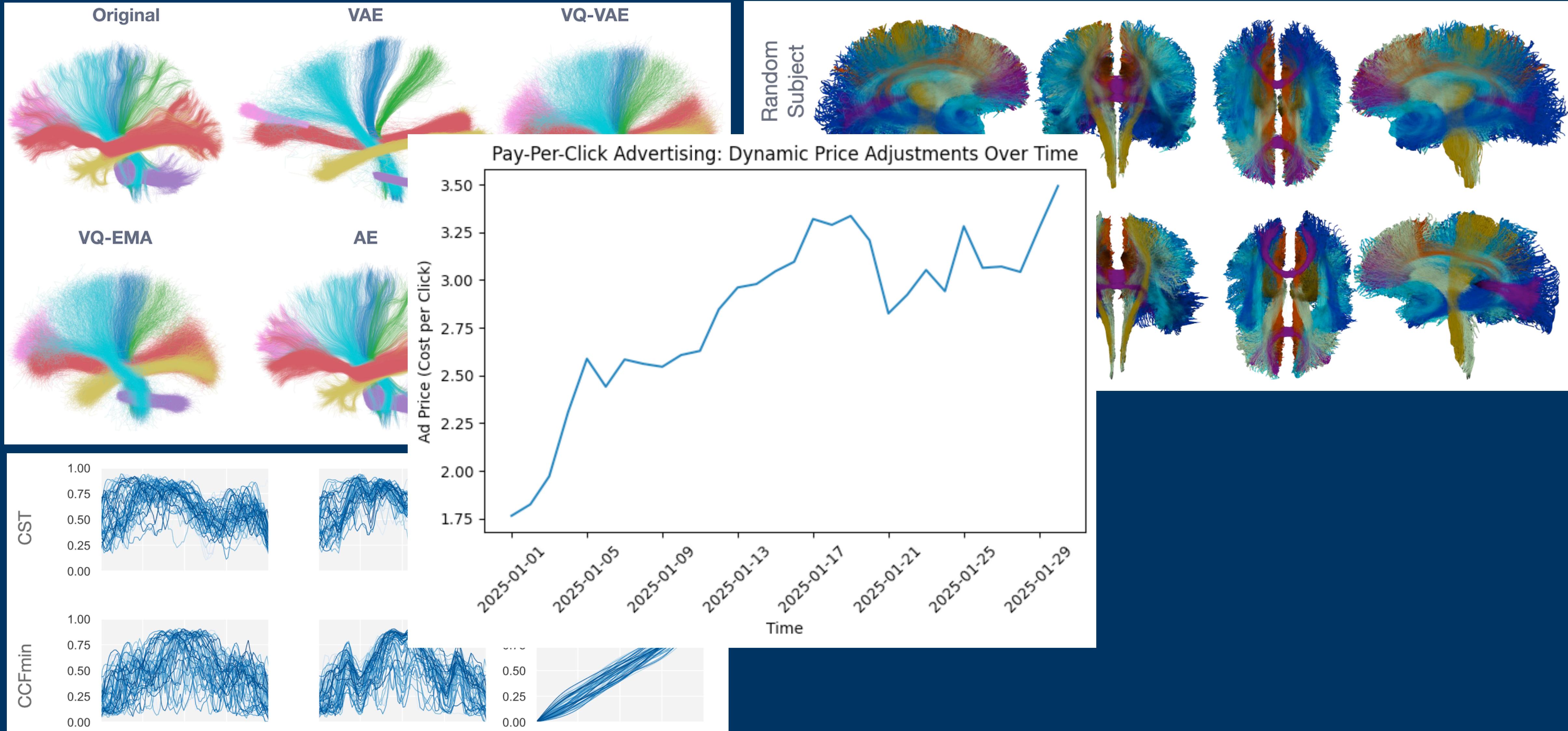
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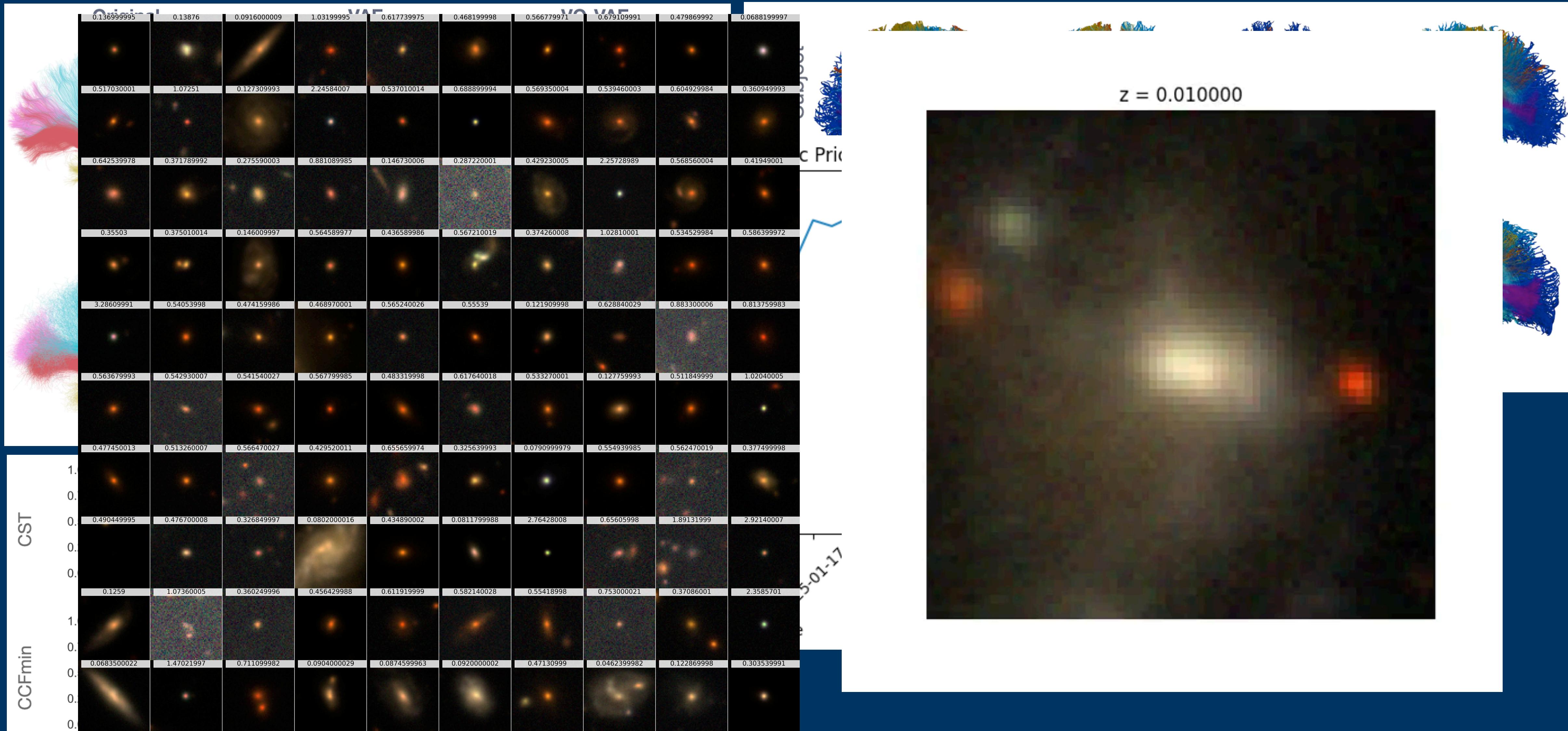
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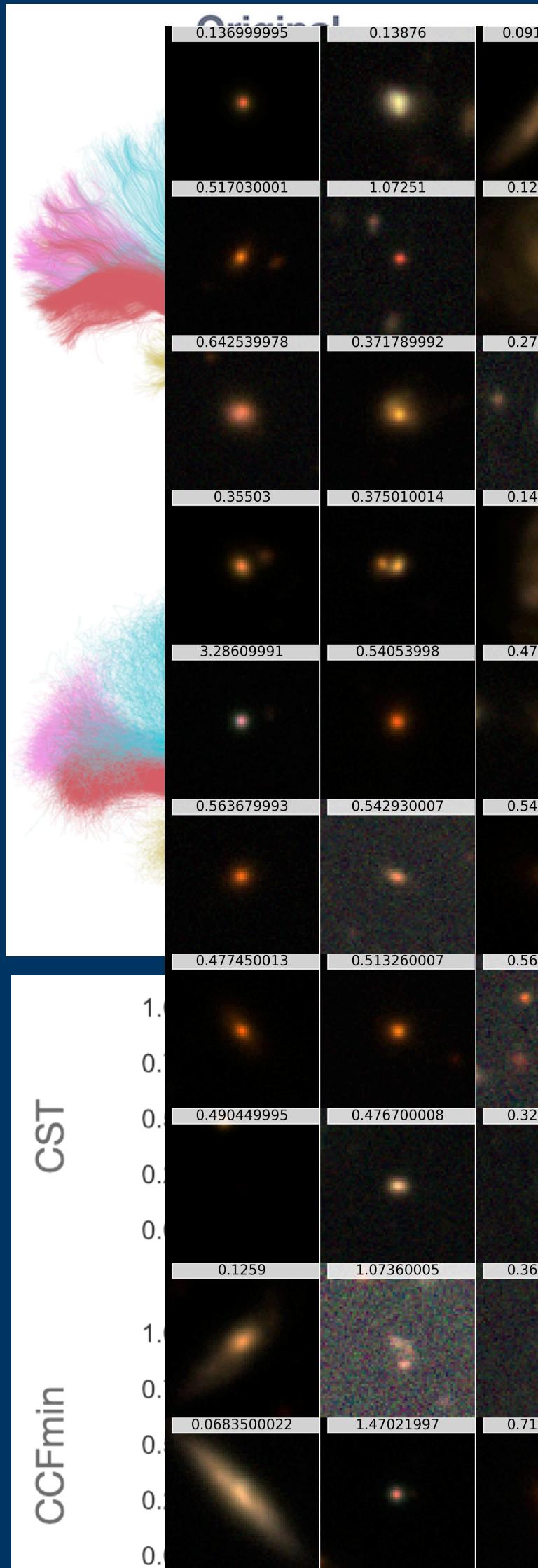
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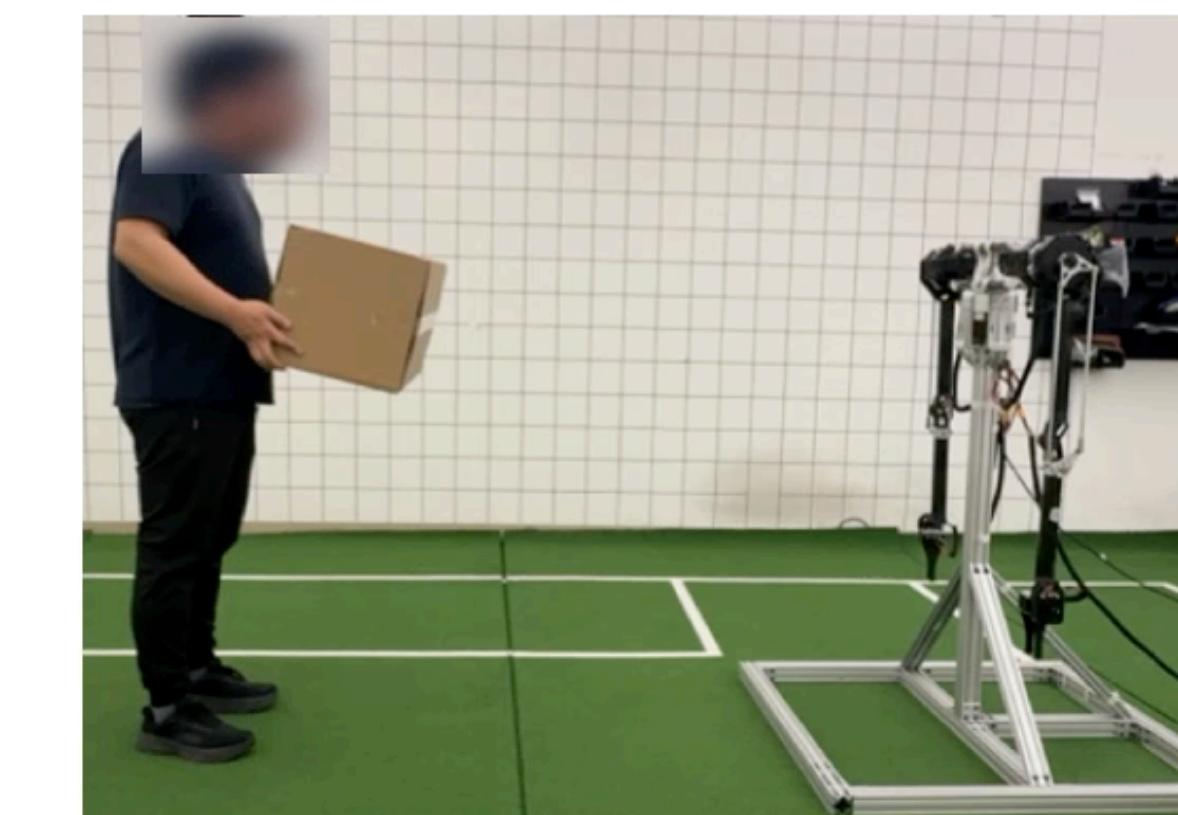


Latent Adaptive Planner: Hardware Testing

Baseline: Diffusion Policy (Best Selected Cases)



Robot A – Box 1



Robot A – Box 2



Robot A – Box 3

Only learned final pose with fine success rates due to task simplicity, with highly noisy execution

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 - Lack of practical programming.
 - Lack of putting theory to practice.
 - Lack of engineering maturity:
 - What's practical?
 - When should you apply a technique or not?
 - Having too complicated of a view on a problem.
 - Having too simple of view on a complicated problem.

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Assumptions:

- I'm assuming you have background in stats, linear algebra, and programming (**you may not have this background**).
- I want everyone to be comfortable with answering questions and actually stating your thought process when answering questions.

High Level Overview of A/B Testing

A/B - Testing

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- What is an A/B test in intuitive terms?

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A/B - Testing

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- When can you perform an A/B test?

A/B - Testing

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- A statistically sound approach to compare two things:

A/B - Testing

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 - Is drug B better than drug A?

A/B - Testing

- **What is an A/B test in intuitive terms?**
- A statistically sound approach to compare two things:
 - Is drug B better than drug A?
 - Do customers prefer product B over product A?

A/B - Testing

- When should you conduct an A/B test?
 - (Many Answers):

A/B - Testing

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 - (Many Answers):
 - When it's not easy to tell if there is a difference between two objects of interest.

A/B - Testing

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A/B - Testing

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 - Is drug B safer than drug A (even marginally so)?
 - Is computer B faster than computer A?
 - Is LLM B better than LLM A at mathematics?

A/B - Testing

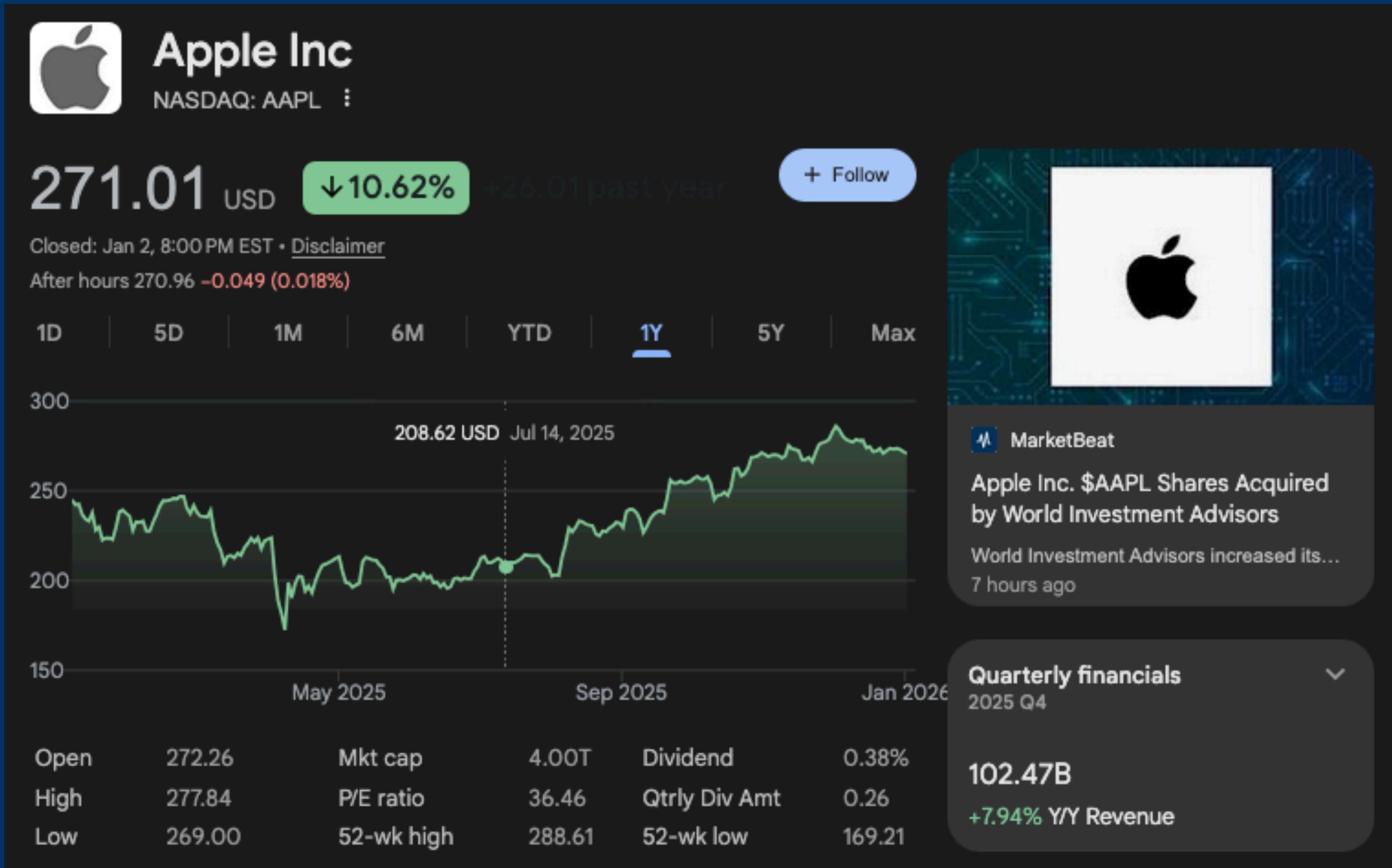
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A/B - Testing

- When can you perform an A/B test?
 - We assume your data is i.i.d. or collected in i.i.d fashion.

A/B - Testing

- Do you think this data is i.i.d?

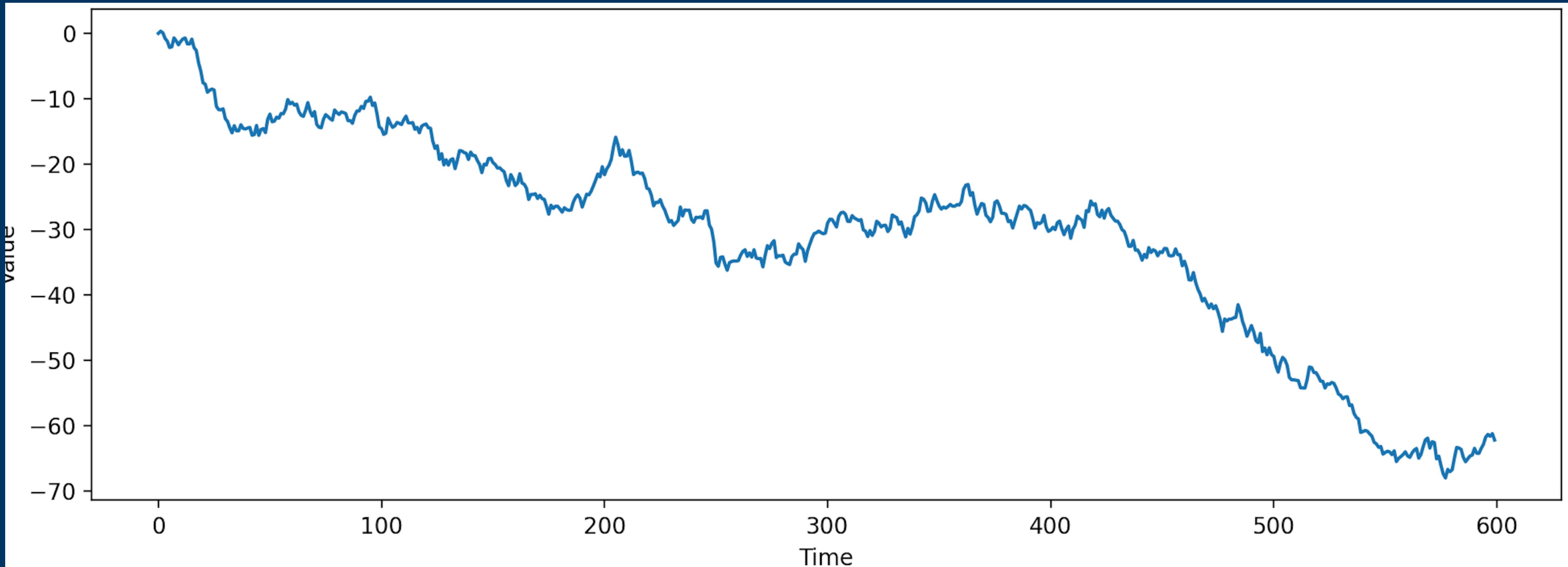


A/B - Testing

- When can you perform an A/B test?
 - We assume your data is i.i.d. or collected in i.i.d fashion.
 - We assume the data is “stationary”, and most business metrics are not stationary, rendering your A/B test dubious at best.

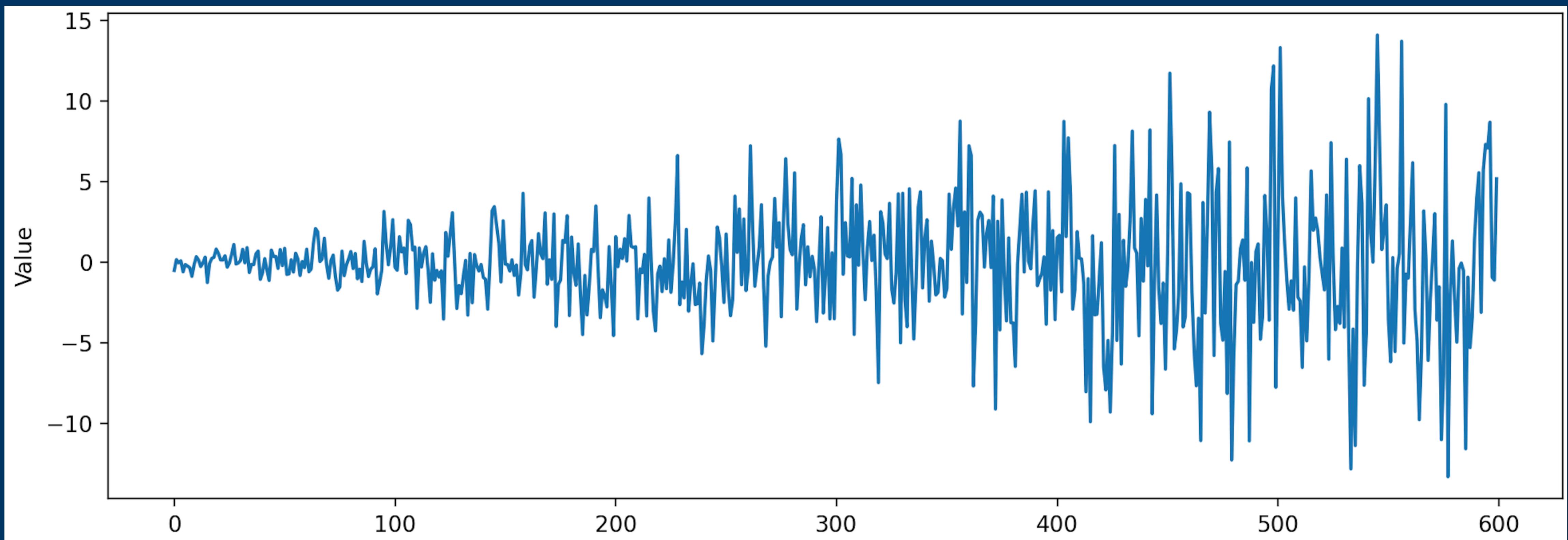
A/B - Testing

- Even if you don't know what it means for data to be “Stationary”, I want you to tell me which of these series seems stationary?



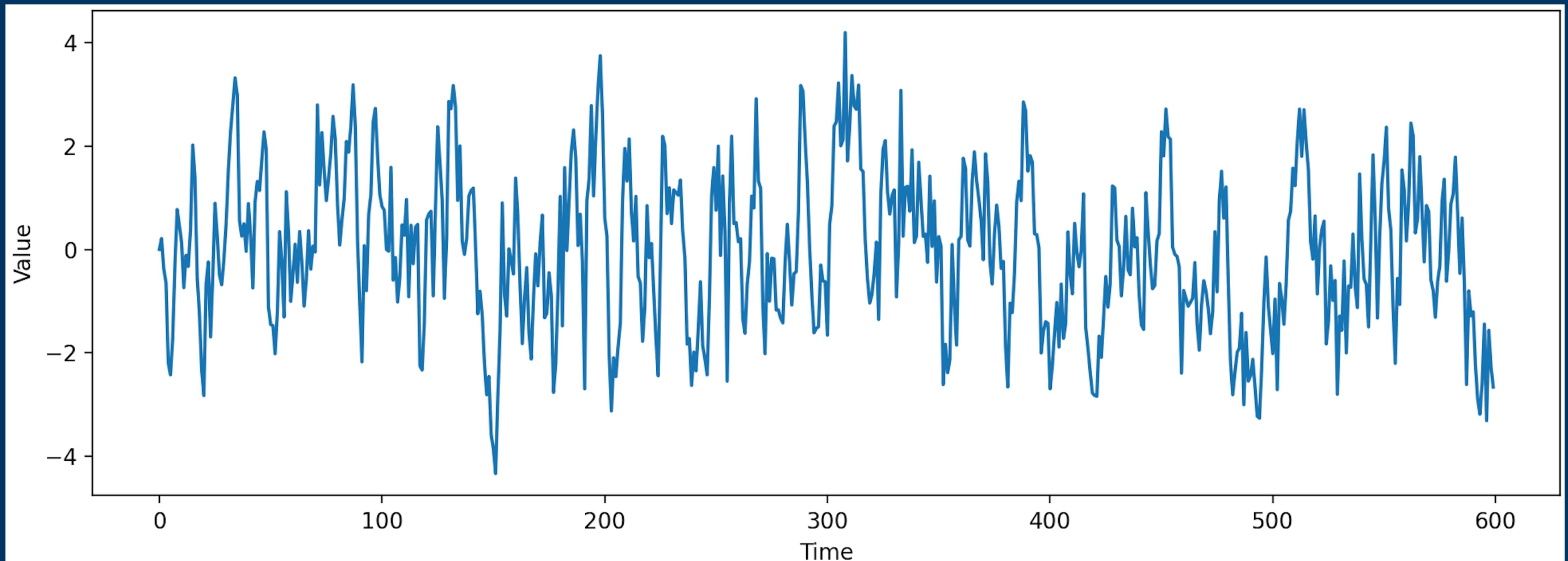
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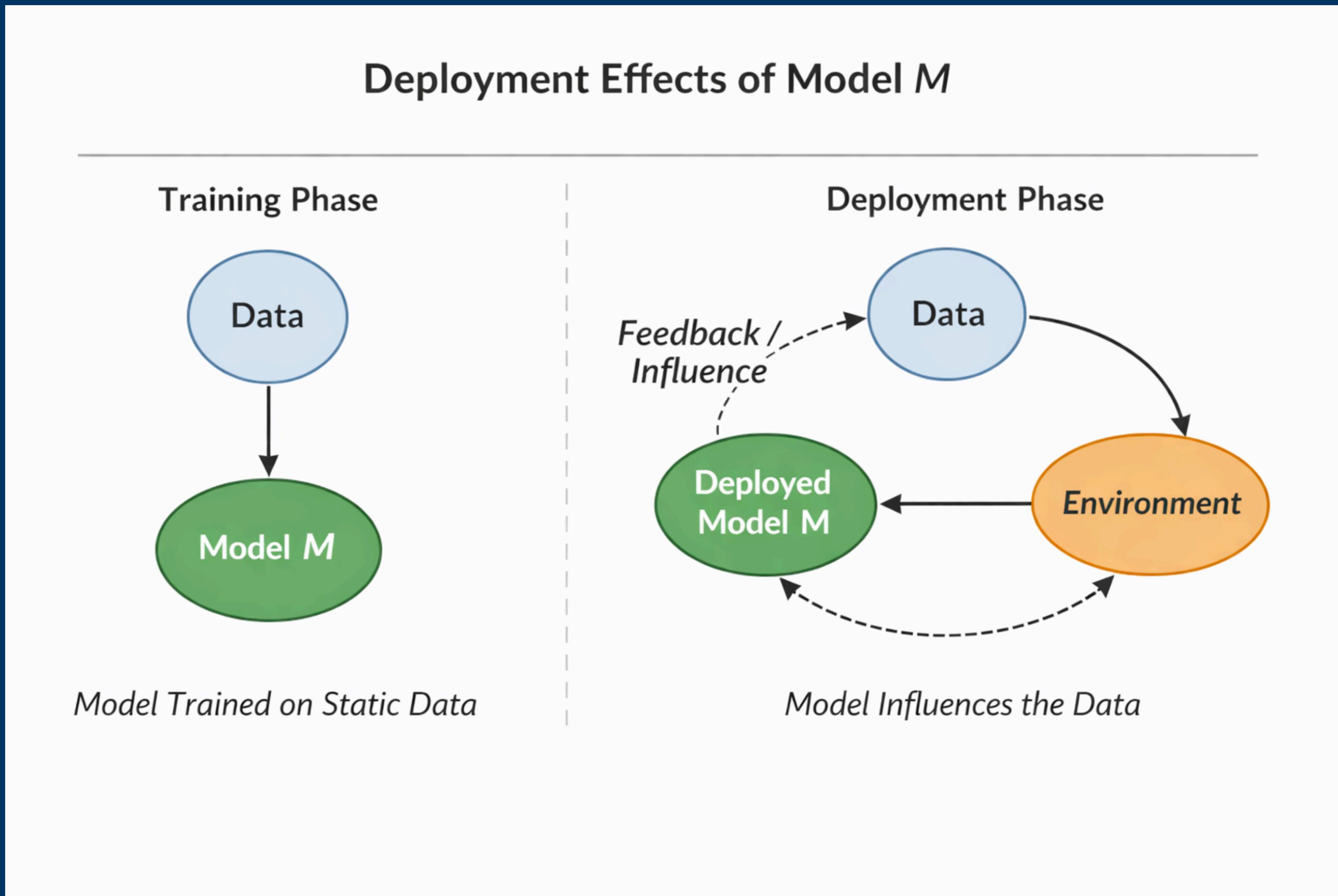


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 - We assume no transient effects.

A/B - Testing

- You train your model on data when your model didn't exist and couldn't influence the data distribution.



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 - We assume the data is “stationary”, and most business metrics are not stationary, rendering your A/B test dubious at best.
 - We assume no transient effects.
 - We assume there is enough signal in the data to draw a meaningful conclusion.

A/B - Testing

- Not enough signal?

- <https://www.tum.de/en/news-and-events/all-news/press-releases/details/40-percent-of-mri-signals-do-not-correspond-to-actual-brain-activity>
- <https://neurosciencenews.com/fmri-neural-activity-30057/>

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fMRI Signals Often Misread Neural Activity

Research | 12/16/2025 | Reading time 3 min.

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fMRI Signals Often Misread Neural Activity

Neuroscience · December 16, 2025

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Why blood flow is not a reliable indicator of the brain's energy requirements

40 percent of MRI signals do not correspond to actual brain activity

Key Facts:

- **Mismatch Revealed:** In roughly 40% of cases, higher fMRI signals were linked to lower neural activity.
- **Oxygen Efficiency Shift:** Brain regions often meet extra energy demand by extracting more oxygen instead of increasing blood flow.
- **Clinical Impact:** fMRI findings in depression, Alzheimer's, and aging may reflect vascular differences rather than true neural activation changes.

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A/B Test Example

A/B - Testing (Stock Exchange Rates)

- We follow examples (with some modifications) from: `Experimentation for Engineers (From A/B testing to Bayesian optimization` by Tim Sweet

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- We consider a hypothetical example to see if trading AAPL has a lower execution cost on ASDAQ v.s. BYSE.

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- We consider a hypothetical example to see if trading AAPL has a lower execution cost on ASDAQ v.s. BYSE.
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 - For the sake of this experiment, we suspect that it might be cheaper to trade on BYSE.
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 - We perform a very simple simulation to demonstrate what an A/B test looks like under ideal conditions.
 - For the sake of this experiment, we suspect that it might be cheaper to trade on BYSE.
 - What should we do before running this test?
-
- We follow examples (with some modifications) from: `Experimentation for Engineers (From A/B testing to Bayesian optimization` by Tim Sweet

- Before running an A/B test, simulate one first.

A/B - Testing (Stock Exchange Rates)

- Before experimenting on real data and potentially losing money. How can we simulate this experiment?

```
1 def trading_system(exchange: str) -> float:  
2     if exchange == "ASDAQ":  
3         execution_cost = 12.0  
4     elif exchange == "BYSE":  
5         execution_cost = 10.0  
6     else:  
7         raise ValueError("Exchange Not supported")  
8     execution_cost += np.random.normal()  
9     return execution_cost
```

A/B - Testing (Stock Exchange Rates)

- Running the exchange once. Can we conclude that B is better than A?

```
np.random.seed(17)
print(trading_system("ASDAQ"))
print(trading_system("BYSE"))
```

```
12.27626589002132
8.145371921193496
```

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```
np.random.seed(18)
print(trading_system("ASDAQ"))
print(trading_system("BYSE"))
```

```
12.079428443806204
12.190202357414222
```

A/B - Testing (Stock Exchange Rates)

- If a single comparison isn't enough, what should we do?

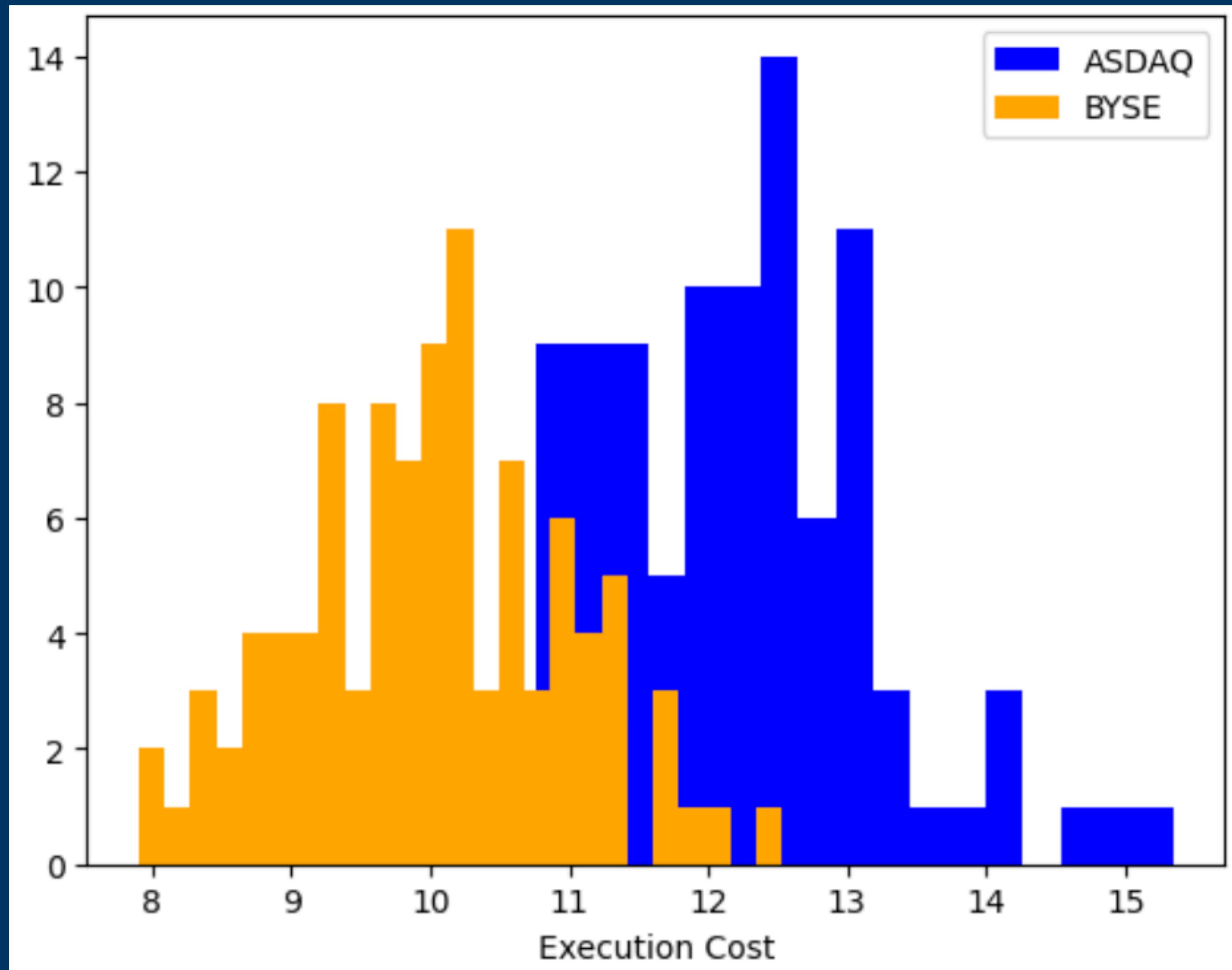
A/B - Testing (Stock Exchange Rates)

- If a single comparison isn't enough, what should we do?

```
1 np.random.seed(17)
2 a = np.array([trading_system("ASDAQ") for _ in range(100)])
3 b = np.array([trading_system("BYSE") for _ in range(100)])
4
5 plt.hist(a, 25, color ='blue')
6 plt.hist(b, 25, color ='orange')
7 plt.legend(["ASDAQ", "BYSE"])
8 plt.xlabel("Execution Cost")
9 plt.show()
```

A/B - Testing (Stock Exchange Rates)

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A/B - Testing (Stock Exchange Rates)

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 - We are assuming our samples are i.i.d.
 - We are assuming that we are sampling a stationary distribution.

A/B - Testing (Stock Exchange Rates)

- What can we conclude?
 - Perhaps the averages of the distributions are different, suggesting that BYSE is cheaper.
 - What assumptions did we make? Is this an appropriate way to run an A/B test?
 - We are assuming our samples are i.i.d.
 - We are assuming that we are sampling a stationary distribution.
 - This is true because we construct the exchanges to have fixed rates, and the variance introduce by the random noise is fixed.

A/B - Testing (Stock Exchange Rates)

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 - Suppose we need a massive amount of measurements to detect the signal:

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 - So we take many measurements of BYSE in the morning.

A/B - Testing (Stock Exchange Rates)

- Are there any problems with our analysis so far?
- Consider a simple example how the time of day can affect our collection of samples:
 - Suppose we need a massive amount of measurements to detect the signal:
 - So we take many measurements of BYSE in the morning.
 - Once that process finishes, we then take many measurements of ASDAQ (now in the afternoon)

- What if trading regardless of exchange is cheaper in the afternoon?

A/B - Testing (Stock Exchange Rates)

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- How do we simulate the stock exchanges with this time-of-day (TOD) bias?

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- How do we simulate the stock exchanges with this time-of-day (TOD) bias?

```
1 def trading_system_tod(exchange: str, time_of_day: str) -> float:
2     ...
3     Trading system with time of day (tod) effect
4     ...
5     if time_of_day == "morning":
6         bias = 2.5
7     elif time_of_day == "afternoon":
8         bias = 0.0
9     else:
10        raise ValueError('Not a valid time of day!')
11    return trading_system(exchange) + bias
```

A/B - Testing (Stock Exchange Rates)

- Compare the exchanges with TOD effect.

A/B - Testing (Stock Exchange Rates)

- Compare the exchanges with TOD effect.

```
np.random.seed(17)
print(np.array([trading_system_tod("BYSE", "morning") for _ in range(100)]).mean())
print(np.array([trading_system_tod("ASDAQ", "afternoon") for _ in range(100)]).mean())
```

A/B - Testing (Stock Exchange Rates)

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print(np.array([trading_system_tod("ASDAQ", "afternoon") for _ in range(100)]).mean())
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12.611509794247766
12.008382946497411

A/B - Testing (Stock Exchange Rates)

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- The remedy for this is to introduce randomization.

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- If we didn't think about the TOD effect we'd conclude that ASDAQ is cheaper than BYSE (which is wrong).
- This is known as a **confounder bias**.
- The remedy for this is to introduce randomization.
- To mitigate bias effects that we may or may not be aware of, it's always a good idea to compare random samples of the data. (**This is a very common mistake I see in a lot of businesses**).

A/B - Testing (Stock Exchange Rates)

- But it takes a long time to run our system, If we take the A samples first, it will take all morning, before we can start sampling B. How do we fix this?

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 - H → Sample from ASDAQ.

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- But it takes a long time to run our system, If we take the A samples first, it will take all morning, before we can start sampling B. How do we fix this?
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 - H → Sample from ASDAQ.
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A/B - Testing (Stock Exchange Rates)

- But it takes a long time to run our system, If we take the A samples first, it will take all morning, before we can start sampling B. How do we fix this?
- Every time the system makes a trade, it flips a coin:
 - H → Sample from ASDAQ.
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 - So about half of the morning trades are on A, and the other half are on B.

A/B - Testing (Stock Exchange Rates)

- But it takes a long time to run our system, If we take the A samples first, it will take all morning, before we can start sampling B. How do we fix this?
- Every time the system makes a trade, it flips a coin:
 - H → Sample from ASDAQ.
 - T → Sample from BYSE.
 - So about half of the morning trades are on A, and the other half are on B.
 - Likewise about half of the trades on A are in the afternoon, and the other half are on B.

A/B - Testing (Stock Exchange Rates)

- Randomizing Measurements:

```
1 def randomized_measurement():
2     asdaq_measurement = []
3     byse_measurement = []
4     for tod in ["morning", "afternoon"]:
5         for _ in range(100):
6             if np.random.randint(2) == 0:
7                 asdaq_measurement.append(trading_system_tod("ASDAQ", tod))
8             else:
9                 byse_measurement.append(trading_system_tod("BYSE", tod))
10    return (np.array(asdaq_measurement).mean(),
11            np.array(byse_measurement).mean())
12
```

A/B - Testing (Stock Exchange Rates)

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- We see that ASDAQ is more expensive than BYSE (which is correct).

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```

- We see that ASDAQ is more expensive than BYSE (which is correct).
- We don't need to be aware of the TOD effect if we simply introduce randomization.

A/B - Testing (Stock Exchange Rates)

- Means and Variance:
 - We set the avg. exchange rate of ASDAQ to be 12.0.

A/B - Testing (Stock Exchange Rates)

- Means and Variance:
 - We set the avg. exchange rate of ASDAQ to be 12.0.
 - Let's consider what happens if we sample 1 measurement from ASDAQ and compare it to the true rate of 12.0.

A/B - Testing (Stock Exchange Rates)

- Means and Variance:
 - We set the avg. exchange rate of ASDAQ to be 12.0.
 - Let's consider what happens if we sample 1 measurement from ASDAQ and compare it to the true rate of 12.0.
 - Then let's take three samples and then average the samples and then compare to 12.0

A/B - Testing (Stock Exchange Rates)

- Means and Variance:

```
1 np.random.seed(17)
2 measurements = np.array([trading_system("ASDAQ") for _ in range(3)])
3 print(measurements - 12.0)
4 print(measurements.mean() - 12.0)
```

A/B - Testing (Stock Exchange Rates)

- Means and Variance:

```
1 np.random.seed(17)
2 measurements = np.array([trading_system("ASDAQ") for _ in range(3)])
3 print(measurements - 12.0)
4 print(measurements.mean() - 12.0)
```

```
[ 0.27626589 -1.85462808  0.62390111]
-0.3181536924862769
```

A/B - Testing (Stock Exchange Rates)

- Means and Variance:
- We see the mean is very close to the true exchange rate of 12.0

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- Means and Variance:
- We see the mean is very close to the true exchange rate of 12.0
- The individual samples can be as far away as 1.85
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 - The variance of the mean of three samples is smaller than the variance of individual samples.

A/B - Testing (Stock Exchange Rates)

- Means and Variance:
- The function below let's us take a specified number of measurements and then sample an exchange of choice:

```
1 def aggregate_measurement(exchange: str, num_individual_measurements: int) -> float:  
2     individual_measurements = np.array([  
3         trading_system(exchange)                      # take an individual measurement  
4         for _ in range(num_individual_measurements) # multiple times  
5     ])  
6     return individual_measurements.mean()          # then average
```

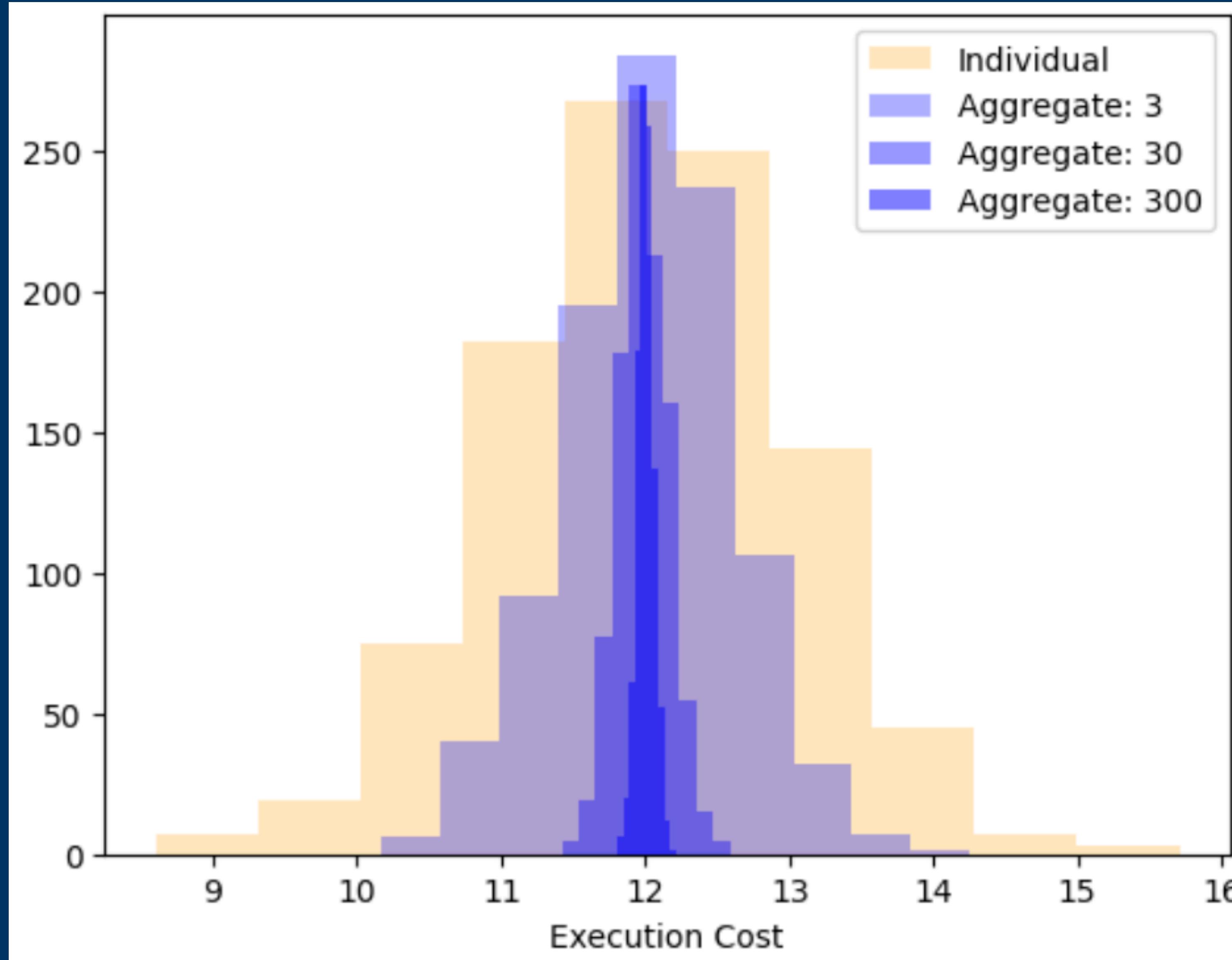
A/B - Testing (Stock Exchange Rates)

- Means and Variance:
- The function below let's us take a specified number of measurements and then sample an exchange of choice:

```
1 np.random.seed(17)
2 plt.hist(np.array([trading_system("ASDAQ")           for _ in range(1000)]), color = 'orange', alpha = 0.25)
3 plt.hist(np.array([aggregate_measurement("ASDAQ", 3) for _ in range(1000)]), color = "blue", alpha = 0.30)
4 plt.hist(np.array([aggregate_measurement("ASDAQ", 30) for _ in range(1000)]), color = "blue", alpha = 0.40)
5 plt.hist(np.array([aggregate_measurement("ASDAQ", 300) for _ in range(1000)]), color = "blue", alpha = 0.50)
6 plt.xlabel("Execution Cost")
7 plt.legend(["Individual", "Aggregate: 3", "Aggregate: 30", "Aggregate: 300"])
8 plt.show()
```

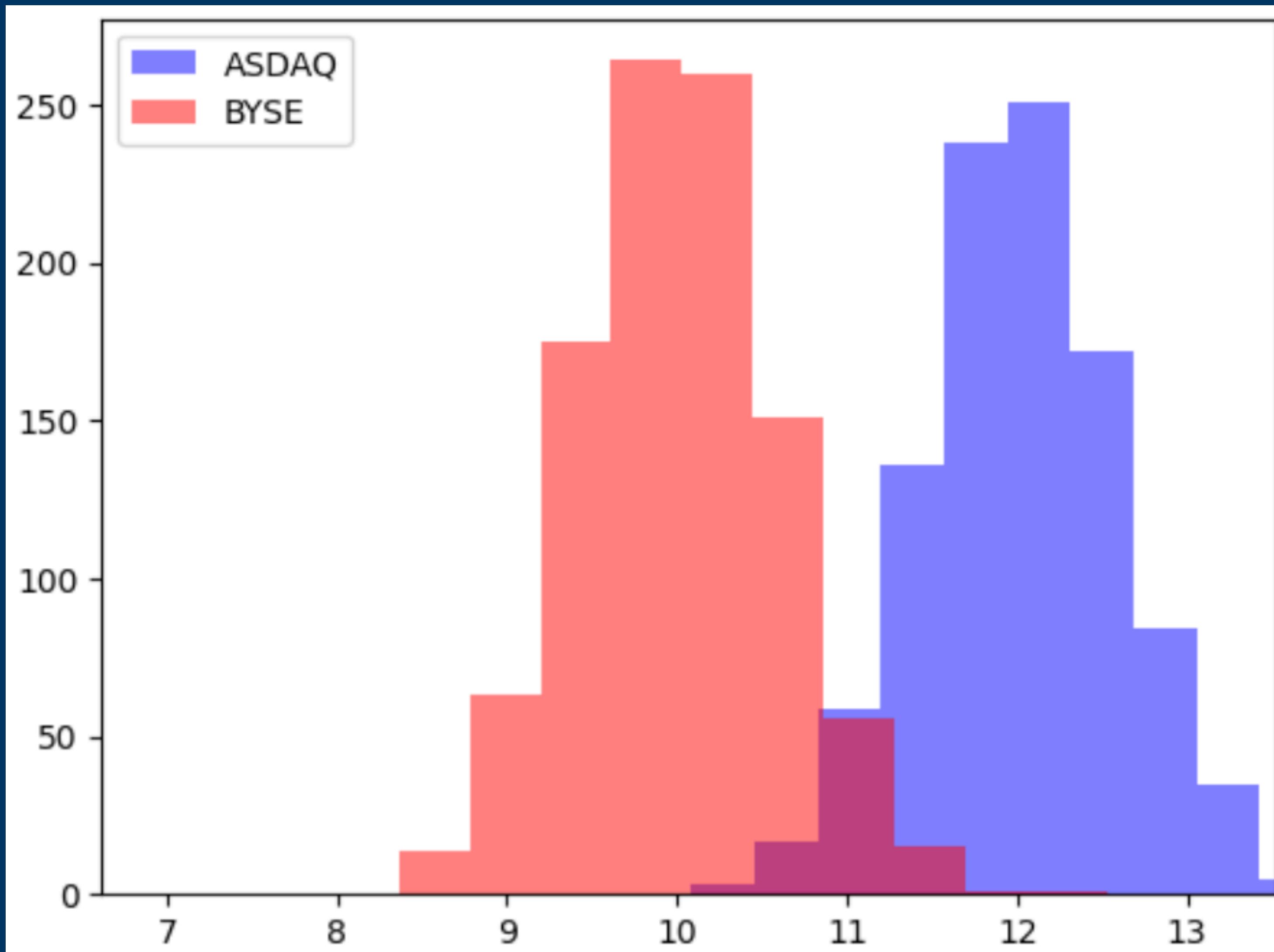
A/B - Testing (Stock Exchange Rates)

- Means and Variance:



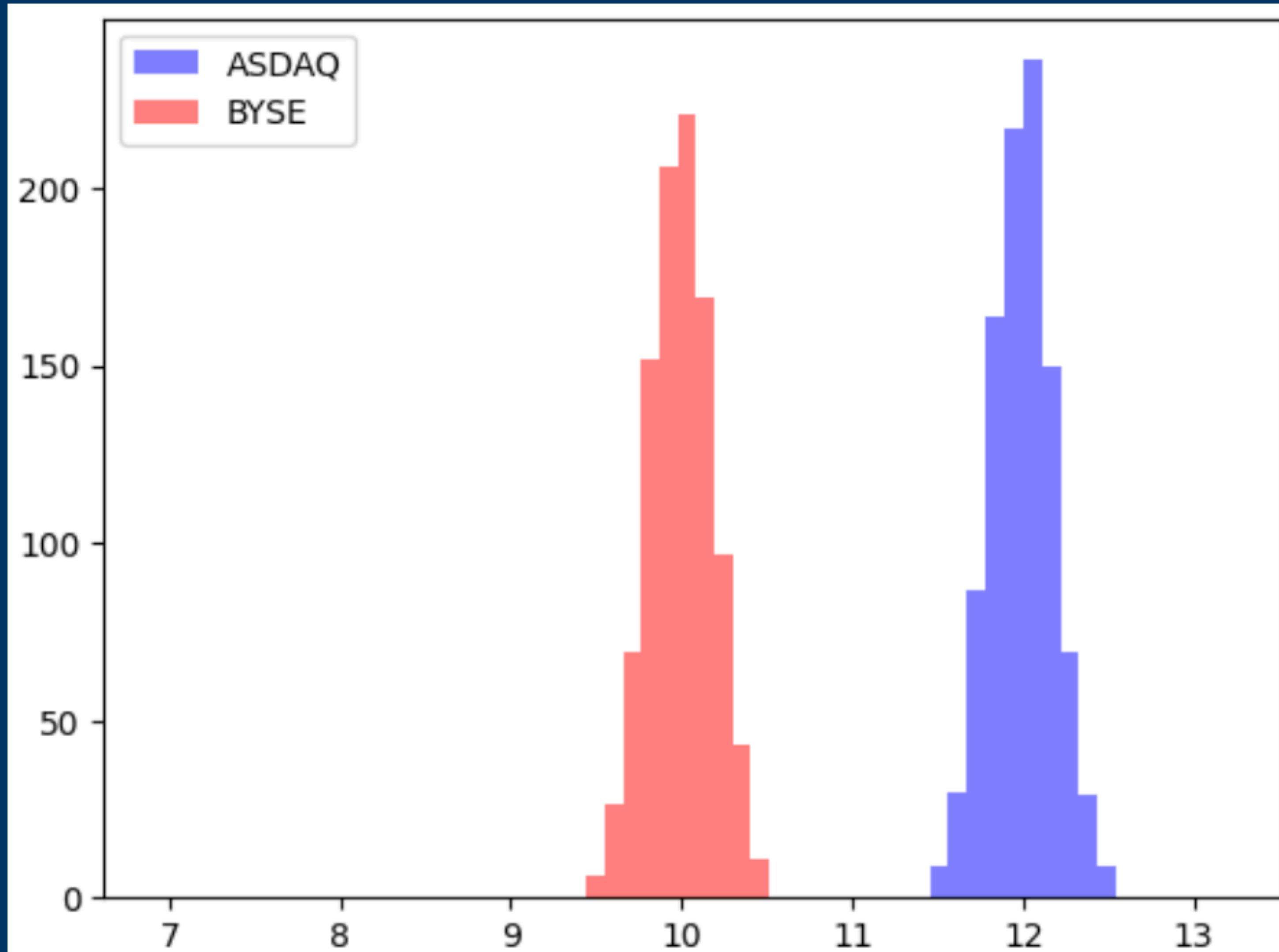
A/B - Testing (Stock Exchange Rates)

- Comparing Two exchanges 3 samples:



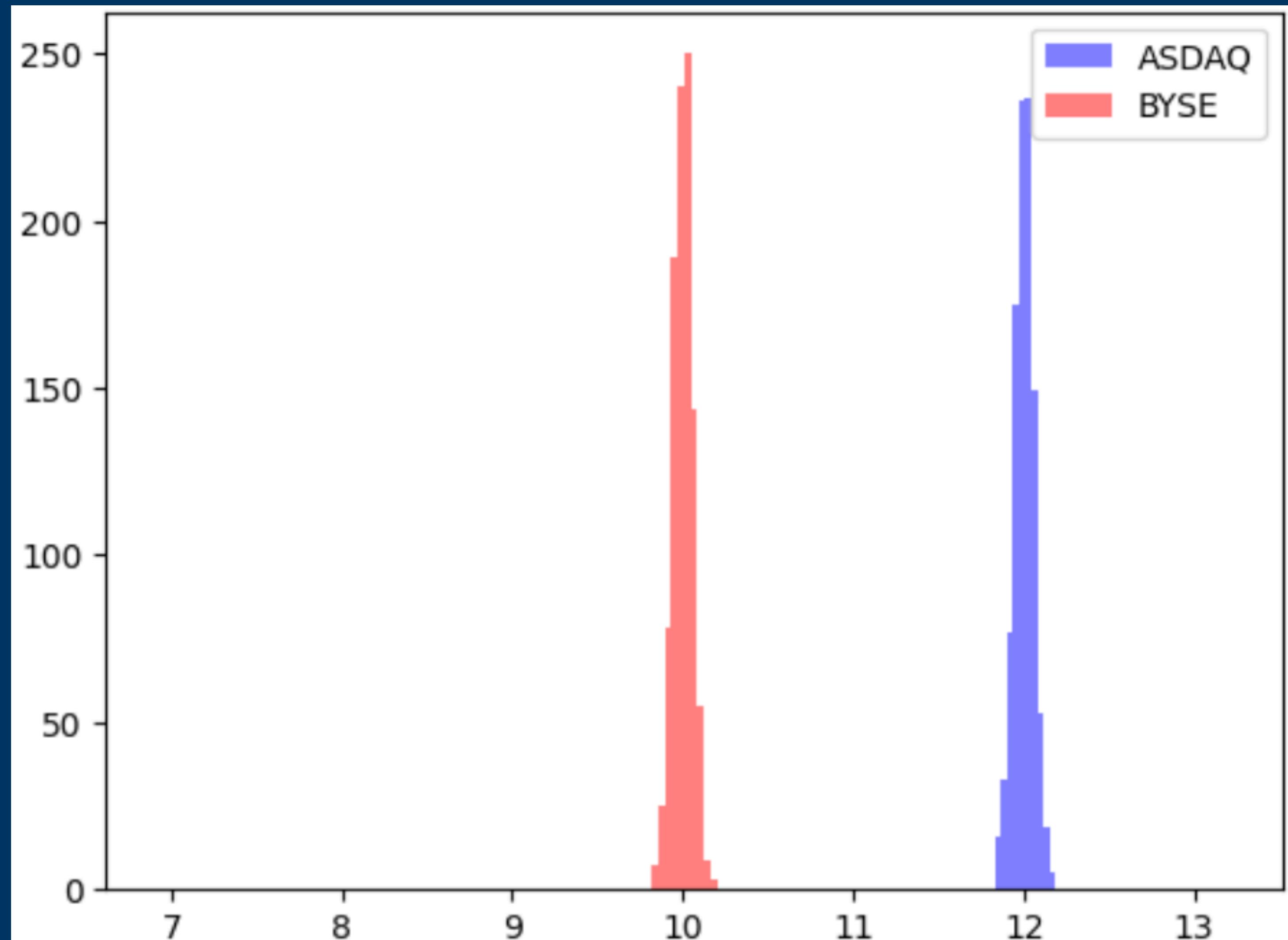
A/B - Testing (Stock Exchange Rates)

- Comparing Two exchanges 30 samples:



A/B - Testing (Stock Exchange Rates)

- Comparing Two exchanges 300 samples:



Thank You

(Up next: SE, z-scores, False Positives, FDR-corrections)

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