Privacy Integrated Data Stream Queries

Lucas Waye

HARVARD
School of Engineering and Applied Sciences

Workshop on Privacy and Security in Programming 2014

Sanitizing Private Data Sets

Sanitizing Private Data Sets

Private

Static Data Set

Sanitizing Private Data Sets

Private

Static Data Set

Sanitizer

Differentially Private

Sanitizing Private Data Sets

Private

Static Data Set

Sanitizer

Differentially Private

Public

Sanitized Output

Sanitizing Private Data Sets

Private

Static Data Set

Sanitizer

Differentially Private

Public

Sanitized Output

Sanitizing Private Data Sets

Private

Static Data Set

- Row database
- Graph
- Bids

Sanitizer

Differentially Private

Public

Sanitized Output

Sanitizing Private Data Sets

Private

Static Data Set

- Row database
- Graph
- Bids

Sanitizer

Differentially Private

Public

Sanitized Output

- Query results
- Synthetic data
- Summary Structure

Sanitizing Private Data Sets

available to non-privacy-experts

Private

Static Data Set

- Row database
- Graph
- Bids

Sanitizer

Differentially Private

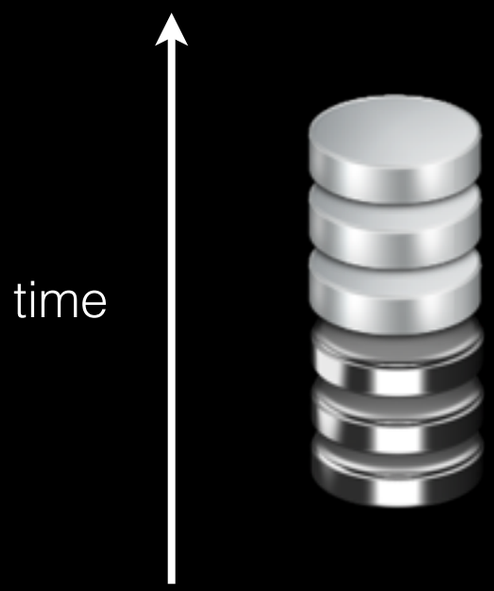
Public

Sanitized Output

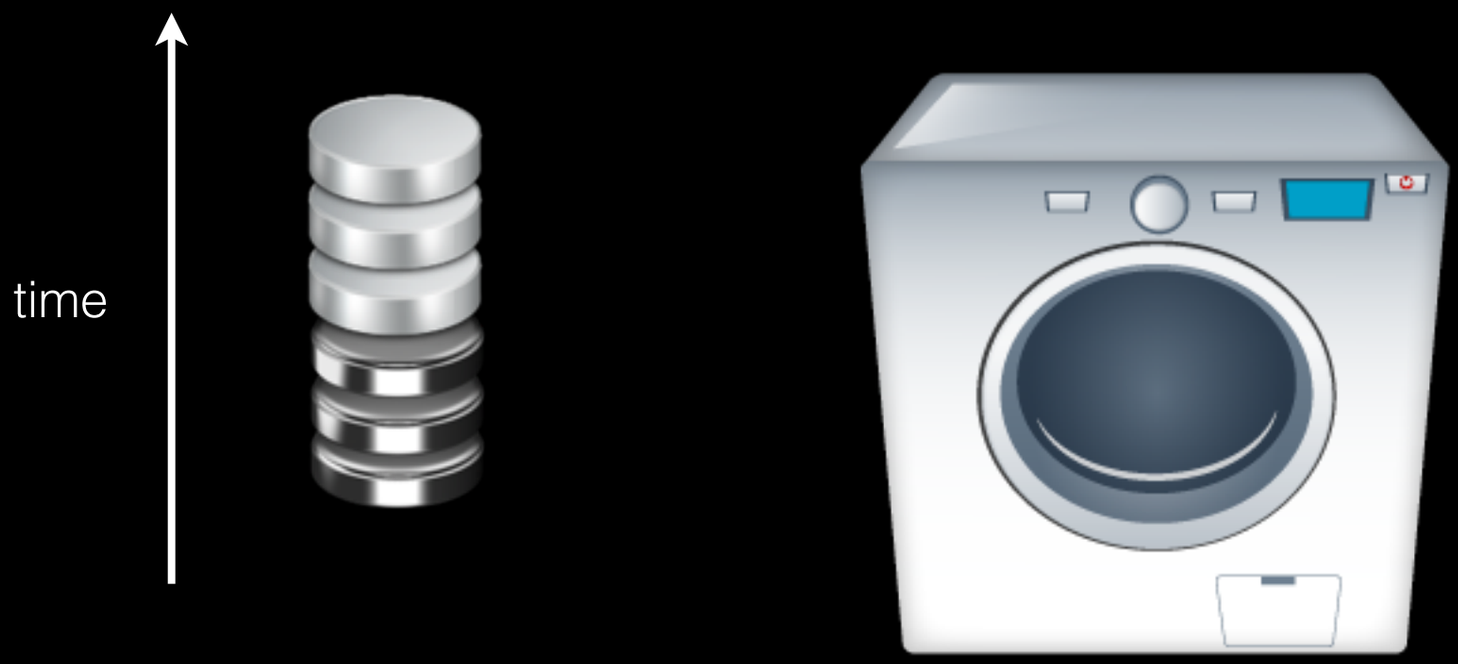
- Query results
- Synthetic data
- Summary Structure

Streaming Data

Streaming Data



Streaming Data



Streaming Data

Streaming Data

Streaming Data

traditional differentially private mechanisms
do not account for new data (“one-shot”)

streaming sanitizers not accessible to non-privacy-experts

Streaming Data

this talk — bringing theory to practice
giving non-experts the ability to sanitize private streaming data

tim

traditional differentially private mechanisms
do not account for new data (“one-shot”)

streaming sanitizers not accessible to non-privacy-experts

Talk Outline

- Background: streaming differential privacy
  - Event-Level privacy
  - User-Level Privacy
- Our setting
- Streaming PINQ
  - Where PINQ falls short
  - Streaming PINQ agents by example
- Conclusions and future work

Differentially Private Streaming Algorithms

Differentially Private Streaming Algorithms

Private
Streaming Input

Public
Streaming Output

Streaming Sanitizer

Privacy Guarantees

it varies!

Privacy Guarantees

it varies!

Privacy Guarantees

it varies!

Based on theoretical output behavior:

The output of the sanitizer does not differ *much* on *neighboring* input streams.

Privacy Guarantees

it varies!

Based on theoretical output behavior:
The output of the sanitizer does not differ *much* on *neighboring* input streams.

Result: hard to notice if a particular individual is present in the data set

Privacy Guarantees

it varies!

Based on theoretical output behavior:
The output of the sanitizer does not differ *much* on *neighboring* input streams.

Result: hard to notice if a particular individual is present in the data set

How *much* does the output differ?

Privacy Guarantees

it varies!

Based on theoretical output behavior:
The output of the sanitizer does not differ *much* on *neighboring* input streams.

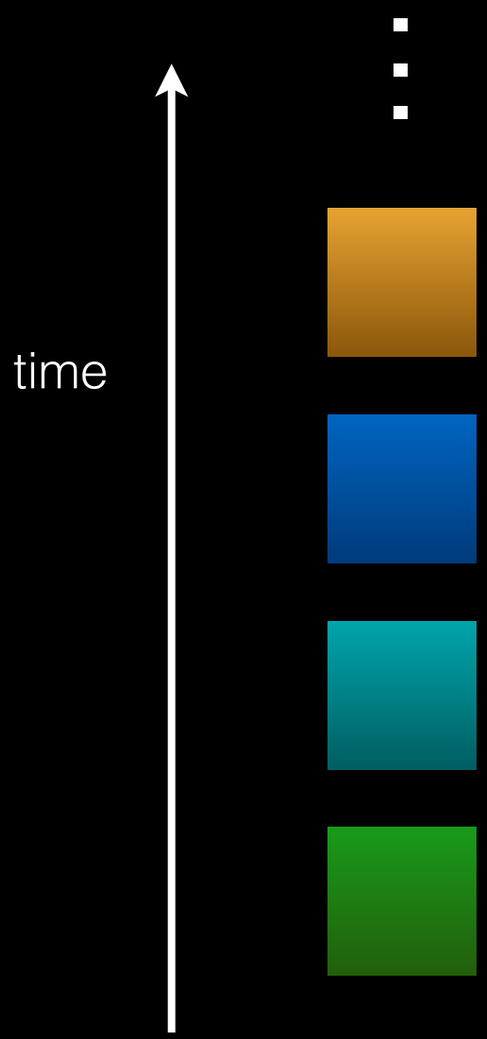
Result: hard to notice if a particular individual is present in the data set

How *much* does the output differ?

What is a *neighboring* input stream?

- event-level privacy
- user-level privacy

Event-Level Privacy*



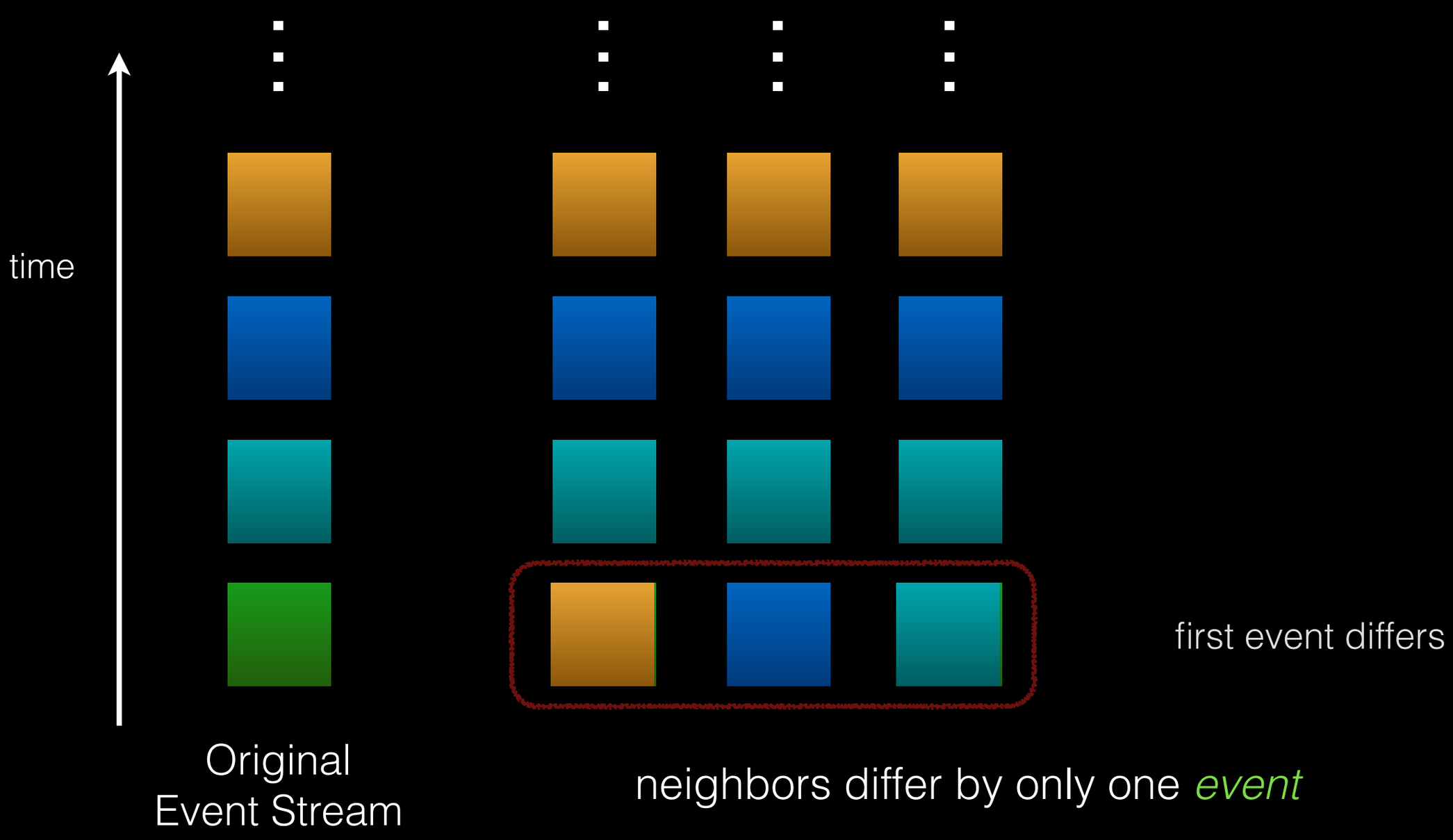
Original
Event Stream

neighbors differ by only one *event*

colors represent different event types

* Dwork et al. 2010

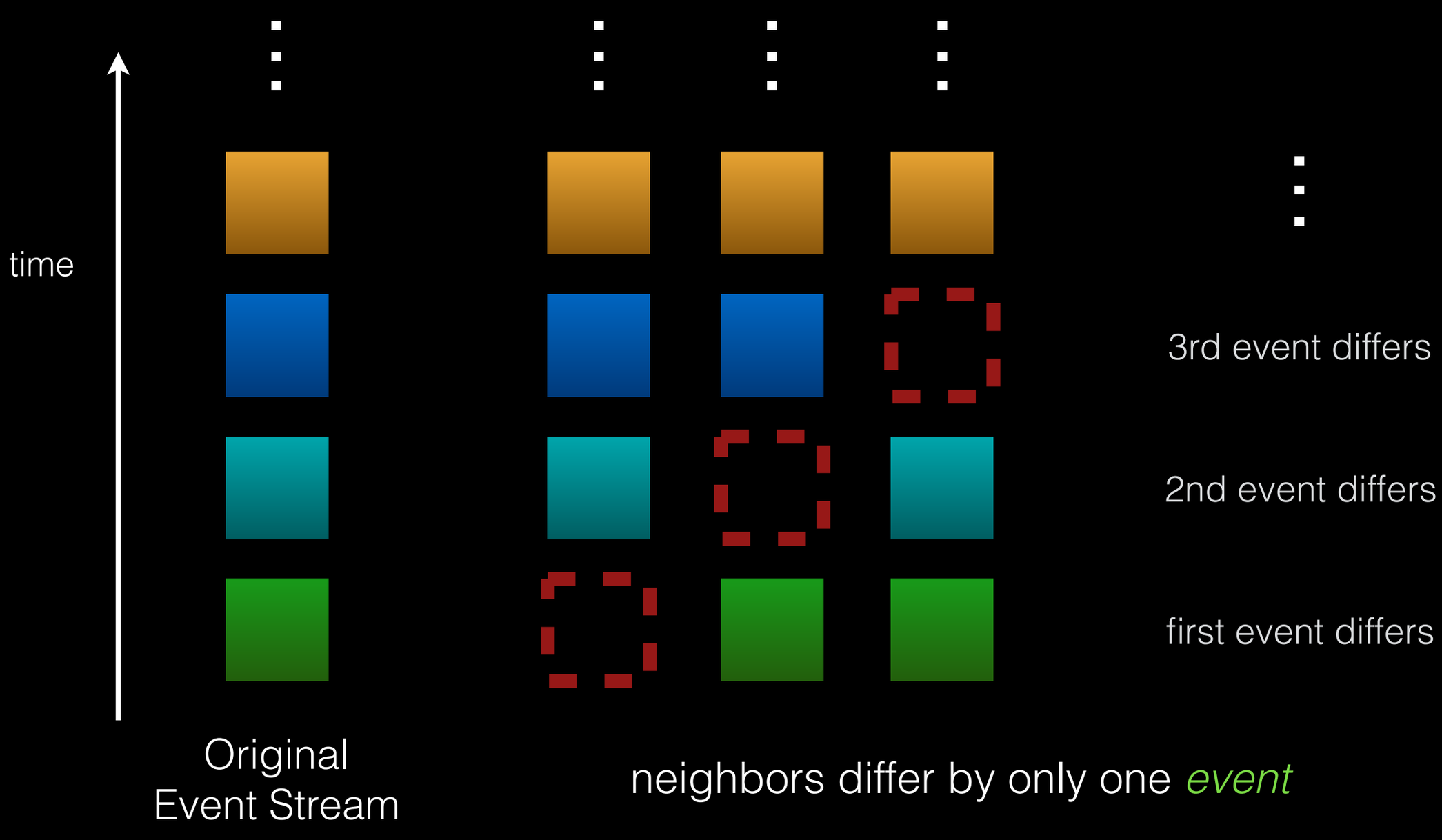
Event-Level Privacy*



colors represent different event types

* Dwork et al. 2010

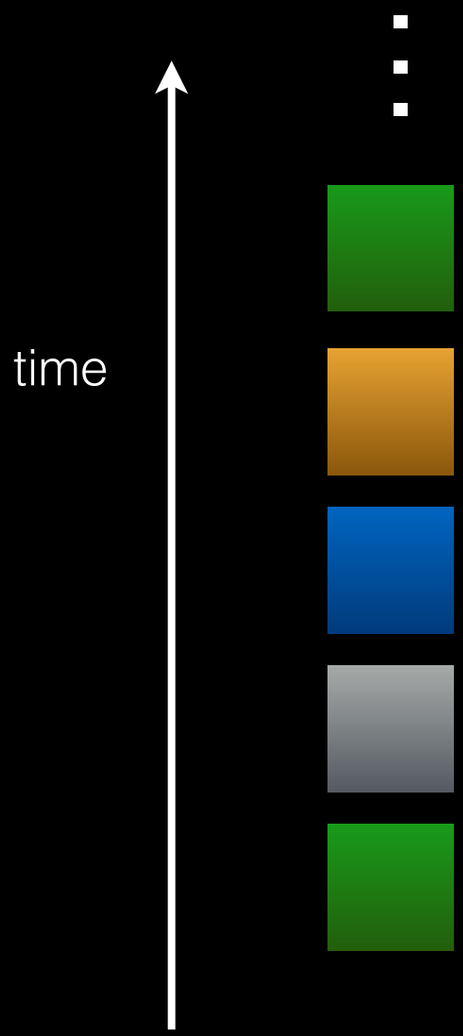
Event-Level Privacy*



colors represent different event types

* Dwork et al. 2010

User-Level Privacy*



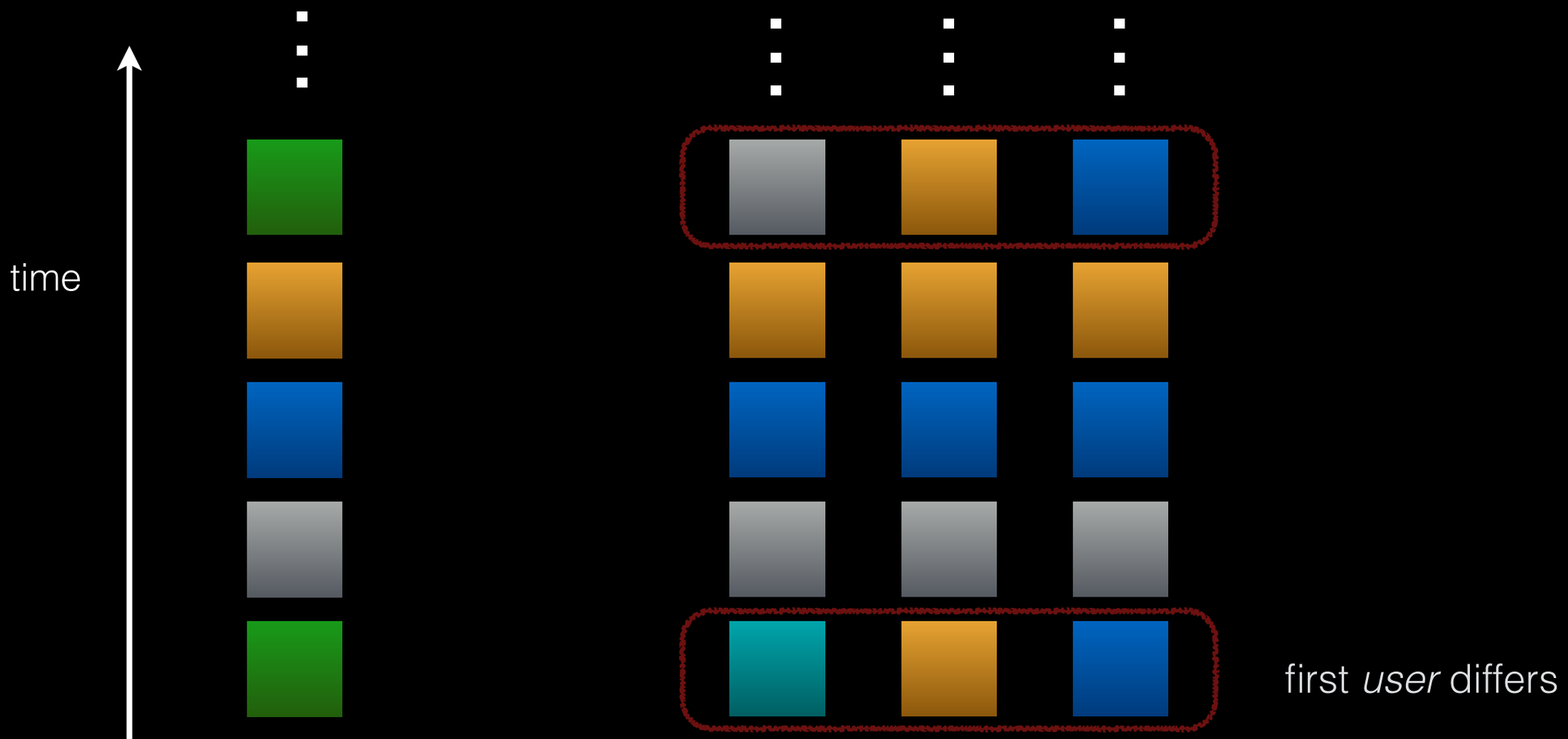
Original
Event Stream

neighbors differ by only one *user*

colors represent different users' events

* Dwork et al 2010

User-Level Privacy*



colors represent different users' events

* Dwork et al 2010

User-Level Privacy*

colors represent different users' events

* Dwork et al 2010

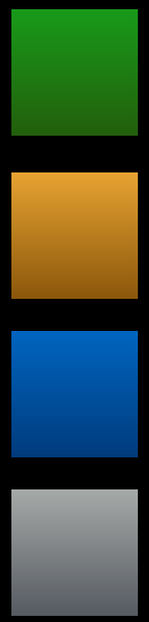
Talk Outline

- Background: streaming differential privacy
  - Event-Level privacy
  - User-Level Privacy
- Our setting
- Streaming PINQ
  - Where PINQ falls short
  - Streaming PINQ agents by example
- Conclusions and future work

Our Setting

Data Owner

Analyst



Private
Streaming Input

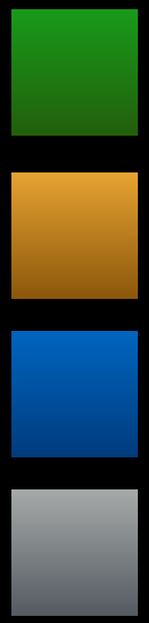
Our Setting

Data Owner

useful information

protect privacy

Analyst



Private
Streaming Input

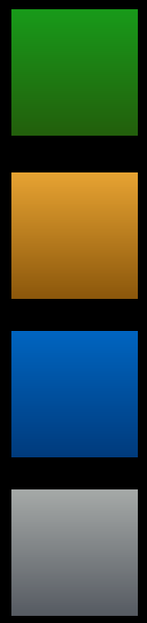
Our Setting

Data Owner

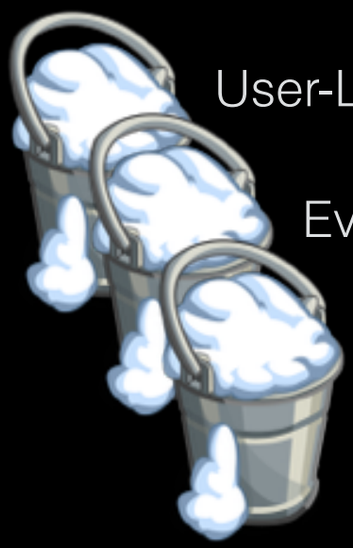
useful information

protect privacy

Analyst



Private
Streaming Input



User-Level Private

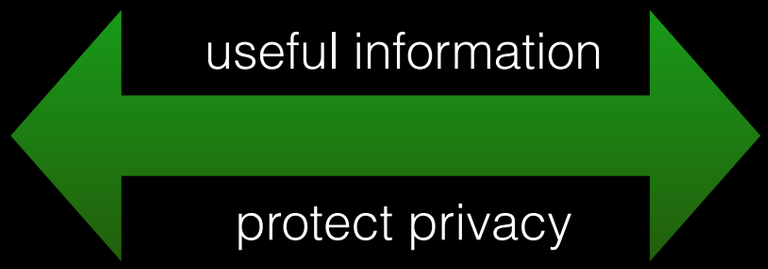
Event-Level Private

Event-Level Private

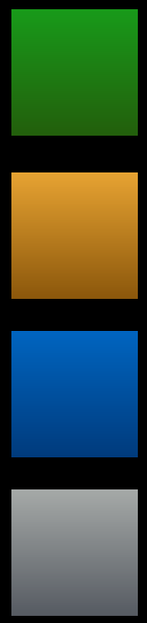
Streaming Sanitizers
with different privacy guarantees

Our Setting

Data Owner

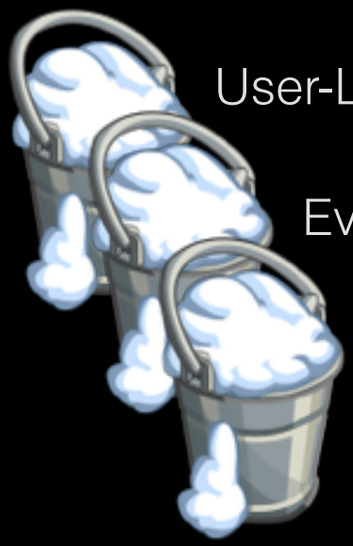


Analyst



Private
Streaming Input

Agent enforces privacy
requirements of data owner



User-Level Private

Event-Level Private

Event-Level Private

Streaming Sanitizers
with different privacy guarantees

Our Setting

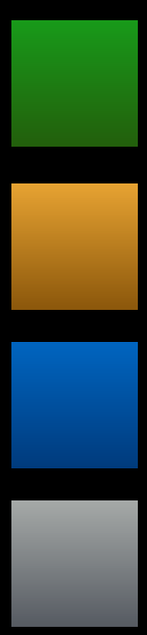
Data Owner

useful information

protect privacy

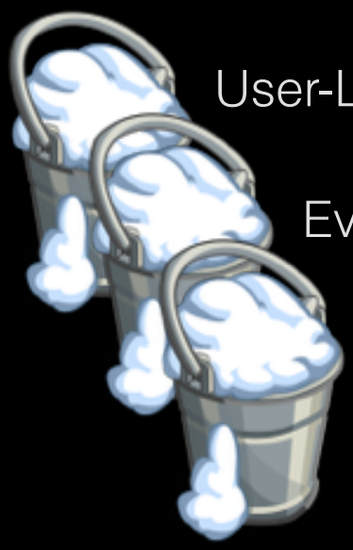
Analyst

selects sanitizers to use



Private
Streaming Input

Agent enforces privacy
requirements of data owner



User-Level Private

Event-Level Private

Event-Level Private

Streaming Sanitizers
with different privacy guarantees

Our Setting

Data Owner

useful information

protect privacy

Analyst

selects sanitizers to use

informs agent of
privacy properties

Agent enforces privacy
requirements of data owner

Private
Streaming Input

User-Level Private

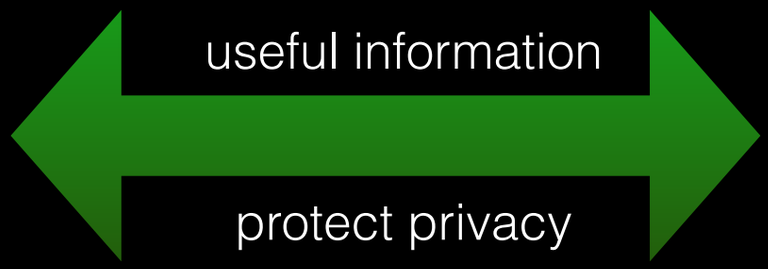
Event-Level Private

Event-Level Private

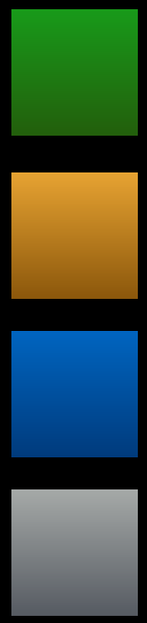
Streaming Sanitizers
with different privacy guarantees

Our Setting

Data Owner

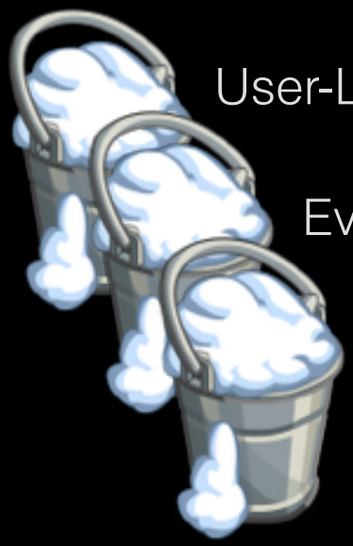


Analyst



Private
Streaming Input

Agent enforces privacy
requirements of data owner



User-Level Private

Event-Level Private

Event-Level Private

Streaming Sanitizers
with different privacy guarantees

Our Setting

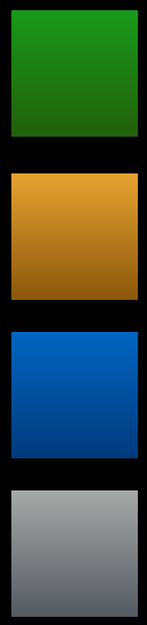
Data Owner

useful information

protect privacy

Analyst

public event



private event

private event

User-Level Private

Event-Level Private

Event-Level Private

Agent enforces privacy
requirements of data owner

Private
Streaming Input

Streaming Sanitizers
with different privacy guarantees

Talk Outline

- Background: streaming differential privacy
  - Event-Level privacy
  - User-Level Privacy
- Our setting
- Streaming PINQ
  - Where PINQ falls short *see paper for how other related work falls short*
  - Streaming PINQ agents by example
- Conclusions and future work

PINQ

Privacy Integrated Query*

```
var tweets = ReadAllSavedTweets("saved_tweets.txt");
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);
```

```
double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

* McSherry 2009

PINQ

Privacy Integrated Query*

Controls how *much* accuracy analyst has
(how *much* privacy is lost)

```
var tweets = ReadAllSavedTweets("saved_tweets.txt");
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);
```

```
double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

* McSherry 2009

PINQ

Privacy Integrated Query*

Controls how *much* accuracy analyst has
(how *much* privacy is lost)

```
var tweets = ReadAllSavedTweets("saved_tweets.txt");
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);
```

```
double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

Control accuracy of result (use up privacy budget)

* McSherry 2009

PINQ: Streaming?

```
var tweets = ReadAllSavedTweets(“saved_tweets.txt”);
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);

double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == ”NY”)
    .NoisyCount(1.0);

Console.WriteLine(”Tweets from New York: ” + tweetsFromNY);
```

PINQ: Streaming?

```
var tweets = ReadAllSavedTweets(“saved_tweets.txt”);
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);

double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == ”NY”)
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

PINQ: Streaming?

```
var tweets = ReadAllSavedTweets(“saved_tweets.txt”);
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);

double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

static data set

PINQ: Streaming?

```
var tweets = ReadAllSavedTweets(“saved_tweets.txt”);
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);

double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

static data set

user-level or event-level?

PINQ: Streaming?

```
var tweets = ReadAllSavedTweets(“saved_tweets.txt”);
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);

double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

static data set

user-level or event-level?

get result immediately

PINQ: Streaming?

```
var tweets = ReadAllSavedTweets("saved_tweets.txt");
var agent = new PINQAgentBudet(1.0);
var data = new PINQueryable<Tweet>(tweets, agent);

double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .NoisyCount(1.0);

Console.WriteLine("Tweets from New York: " + tweetsFromNY);
```

static data set

user-level or event-level?

get result immediately

Contributions

- Support for streaming events
- New agents that are aware of streaming privacy properties
- Five differentially private streaming algorithm implementations

Streaming PINQ

```
var tweets = AllTweetsFireHose();  // custom data provider
var agent = new EventLevelPrivacyBudget(1.0);  // streaming agent
var data = new StreamingQueryable<Tweet>(tweets, agent);

// returns handle to output stream
double tweetsFromNY = data
   .Where(tweet => tweet.Location.State == "NY")
   .RandomizedResponseCount(1.0);

// callback when output is made by algorithm
tweetsFromNY.OnOutput = (c =>
   Console.WriteLine("Tweets from New York: " + c));

// process 5,000 events
tweetsFromNY.ProcessEvents(5000);
```

See paper for:

- description of streaming event API
- implemented streaming algorithms

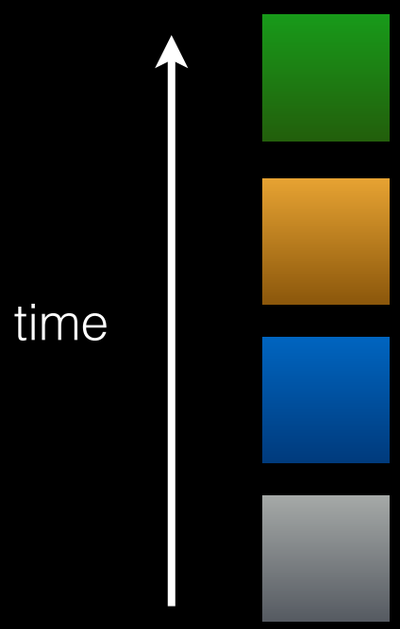
Streaming PINQ

```
var tweets = AllTweetsFireHose();   // custom data provider
var agent = new EventLevelPrivacyBudget(1.0);   // streaming agent
var data = new StreamingQueryable<Tweet>(tweets, agent);

// returns handle to output stream
double tweetsFromNY = data
    .Where(tweet => tweet.Location.State == "NY")
    .RandomizedResponseCount(1.0);

// callback when output is made by algorithm
tweetsFromNY.OnOutput = (c =>
    Console.WriteLine("Tweets from New York: " + c));

// process 5,000 events
tweetsFromNY.ProcessEvents(5000);
```

See paper for:

- description of streaming event API
- implemented streaming algorithms

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

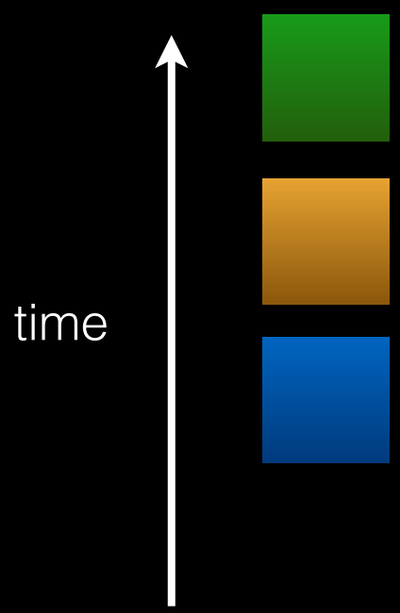
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

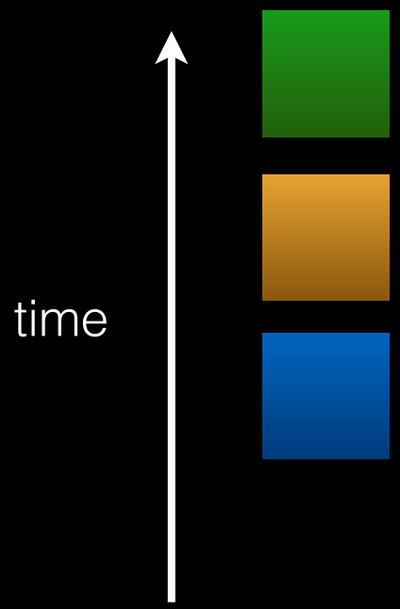
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

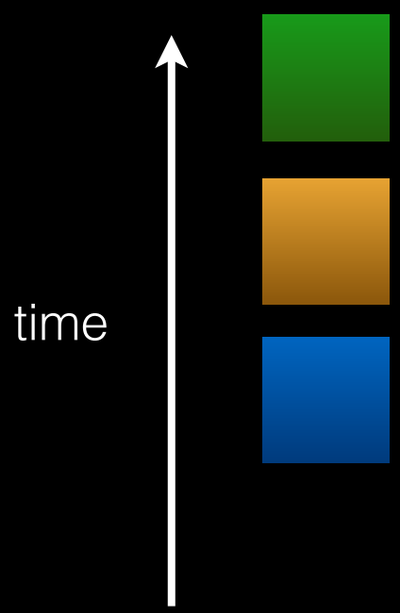
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

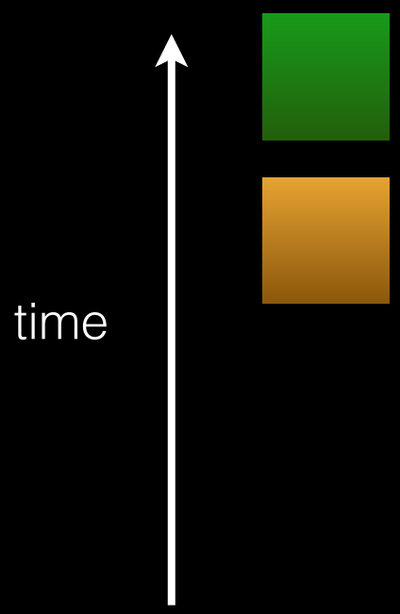
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

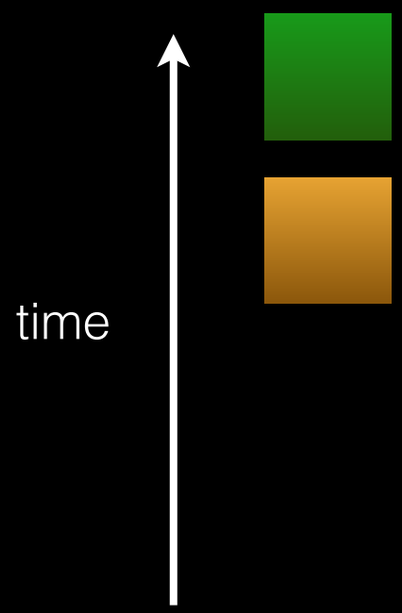
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

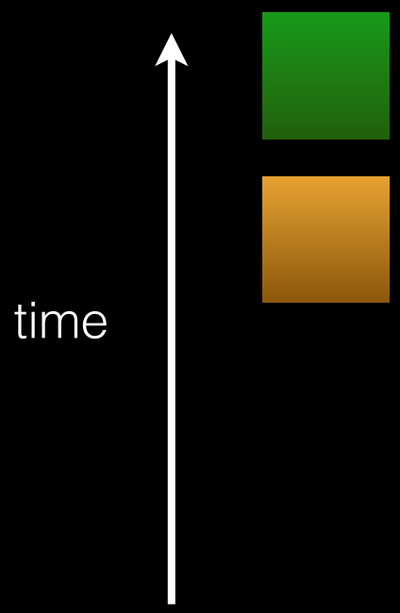
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



Event-Level Agent
Budget = 2ε

User-Level Private

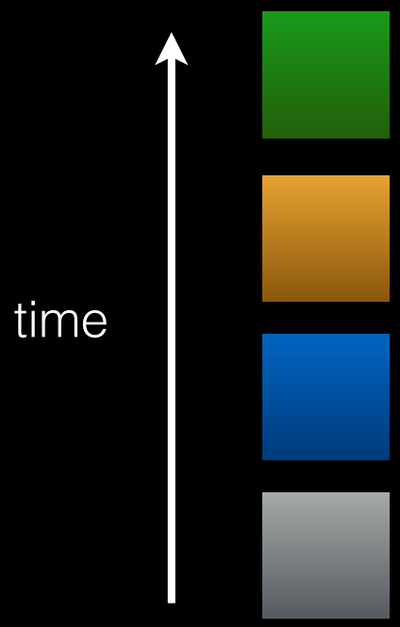
ε privacy

User-Level Privacy implies Event-Level Privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



User-Level Agent
Budget = 2ε

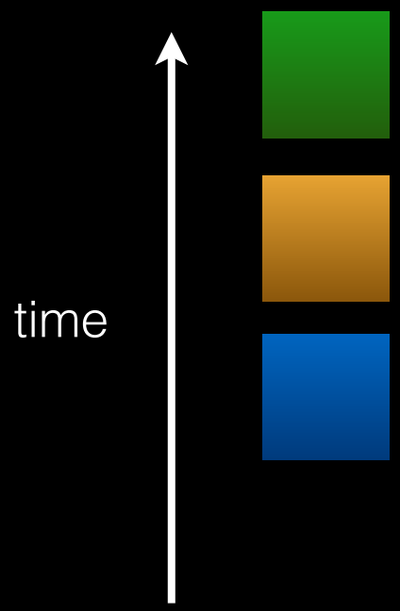
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



User-Level Agent
Budget = 2ε

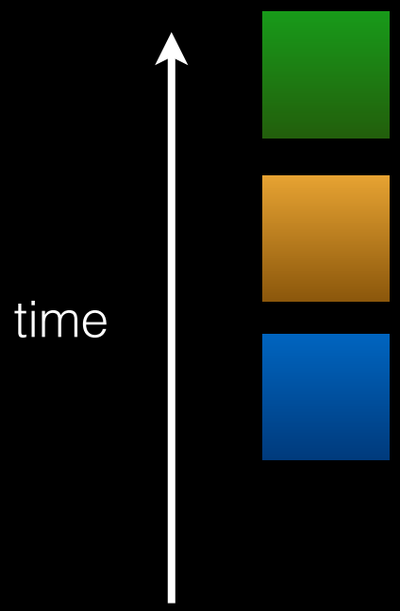
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



User-Level Agent
Budget = 2ε

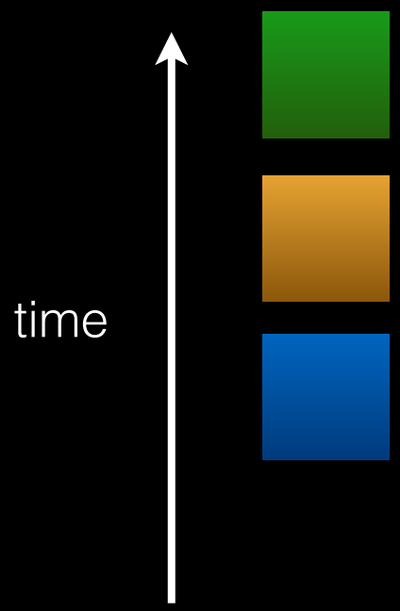
User-Level Private

ε privacy

Event-Level Private

ε privacy

Mixing Privacy Guarantees



User-Level Agent
Budget = 2ε

User-Level Private

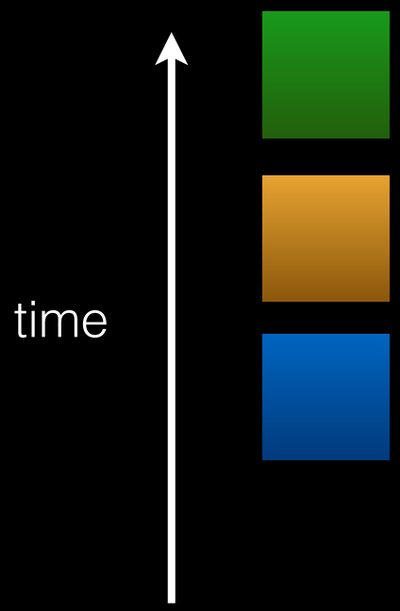
ε privacy

Event-Level Private

ε privacy

privacy of stream permanently affected
event-level treated as a one-time use of user-level algorithm

Mixing Privacy Guarantees



User-Level Agent
Budget *Exhausted*

User-Level Private

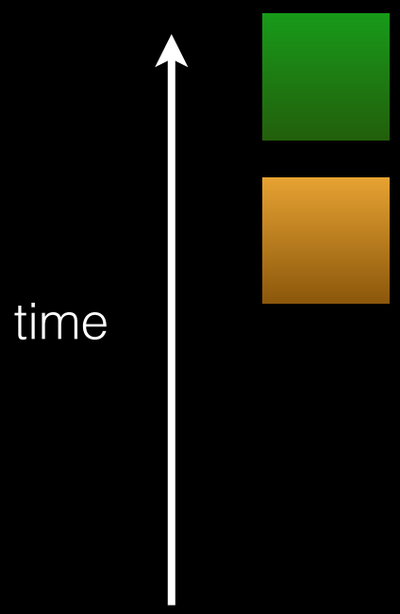
ε privacy

Event-Level Private

ε privacy

privacy of stream permanently affected
event-level treated as a one-time use of user-level algorithm

Mixing Privacy Guarantees



User-Level Agent
Budget *Exhausted*

User-Level Private

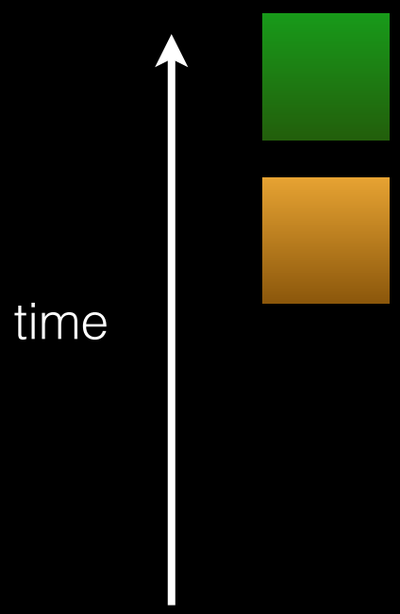
ε privacy

Event-Level Private

ε privacy

privacy of stream permanently affected
event-level treated as a one-time use of user-level algorithm

Mixing Privacy Guarantees



User-Level Agent
Budget *Exhausted*

User-Level Private

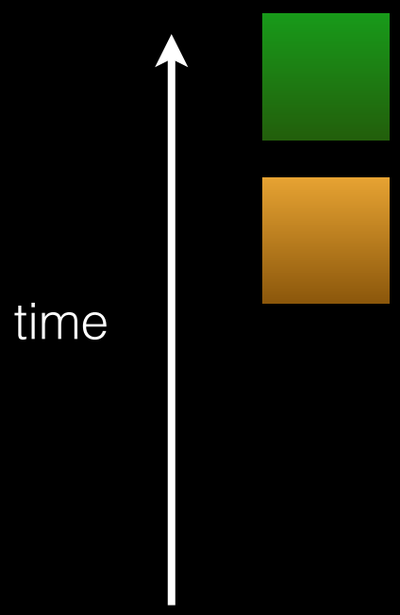
ε privacy

Event-Level Private

ε privacy

privacy of stream permanently affected
event-level treated as a one-time use of user-level algorithm

Mixing Privacy Guarantees



User-Level Agent
Budget *Exhausted*

User-Level Private

ε privacy

Event-Level Private

ε privacy

privacy of stream permanently affected
event-level treated as a one-time use of user-level algorithm

Mixing Privacy Guarantees

see paper for full description of streaming agent API

tim

privacy of stream permanently affected

event-level treated as a one-time use of user-level algorithm

Event-Level Private

ε privacy

Future Work

- Including timing of events in the model
  - Stock trade made after hours → institutional trader
  - Time boxing? Incorporate research on timing channels?
- Large trusted code base
  - Programming framework provides no help in assuring new streaming algorithm implementations are safe
  - C# seems to be the wrong choice of language: many side-channels
  - DSL for streaming queries — what are the right primitives?

Questions?

Thanks!