Oblivious Coopetitive Analytics Using Hardware Enclaves

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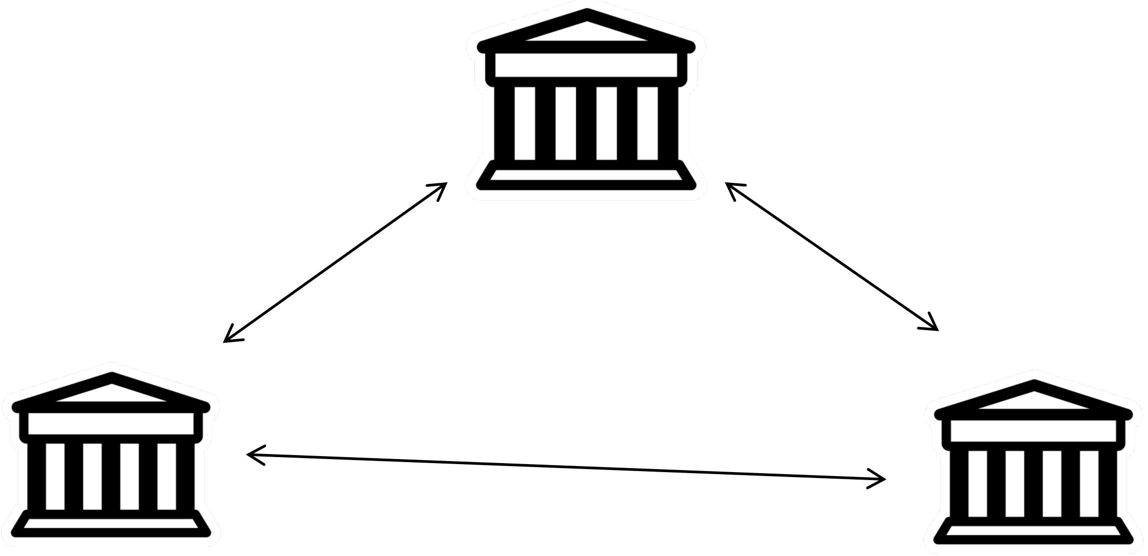
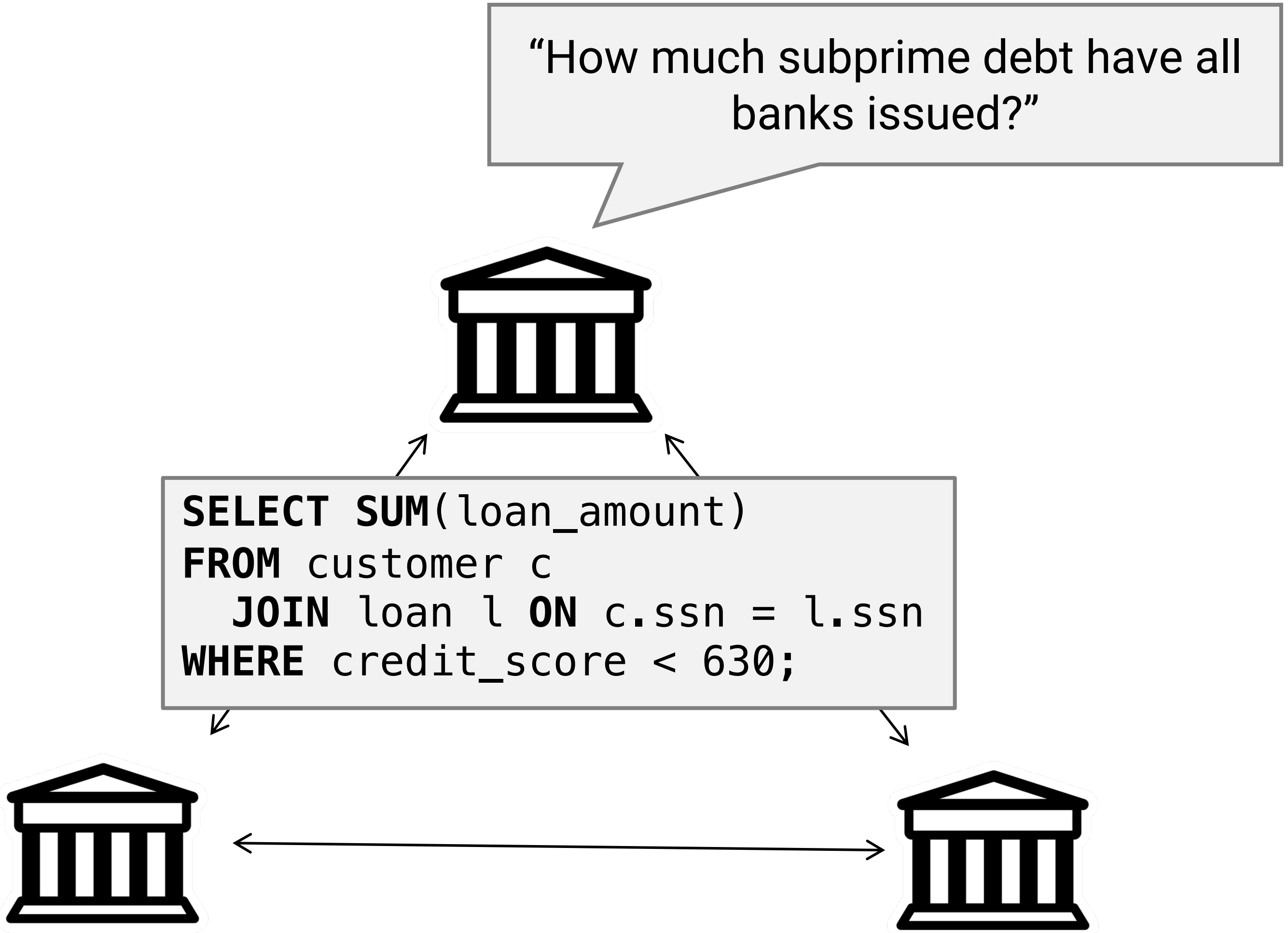
The need for coopetitive analytics

- Analytics can extract value from big data
- But datasets often span multiple competing parties



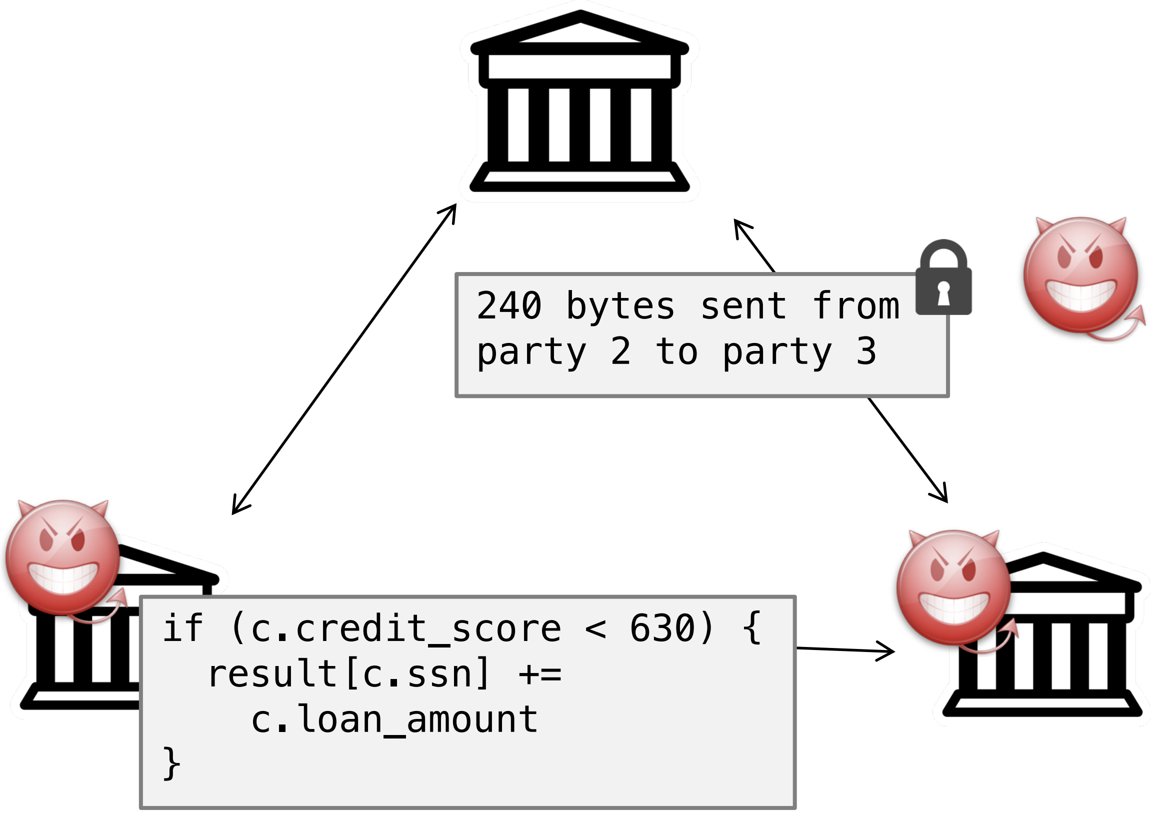
Example: Financial risk assessment

- Banks want to assess systemic risk
- This requires cooperation among competing banks
- Sharing data creates security, regulatory, business, and liability concerns



Threat model

- Network attacker can see and modify all network traffic but cannot access machines
- Malicious party attackers can additionally see and modify computation within their machines + collude with other parties



Approach 1: Cryptography

Specialized systems: Conclave, DJoin, private intersection-sum, Prio, UnLynx, MedCo, …

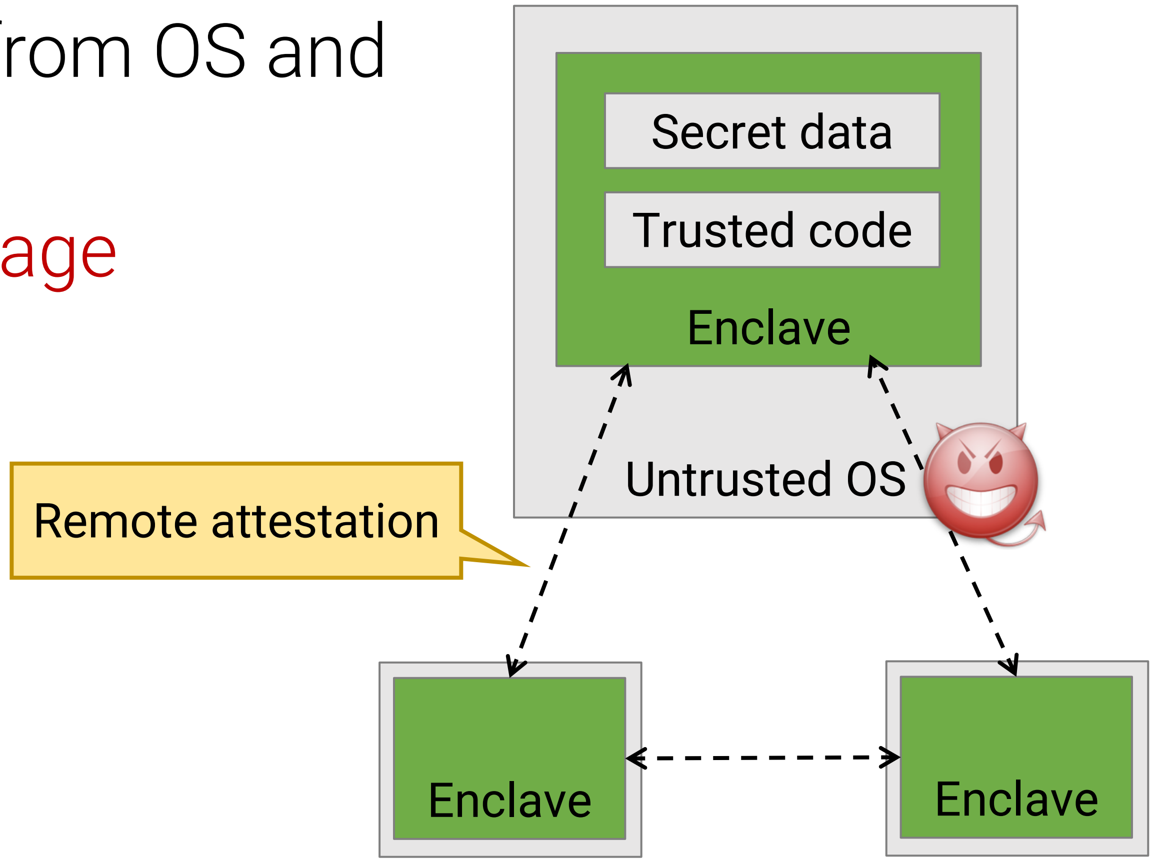
- Limited functionality – cannot support rich analytics

Generic approaches: SMCQL, AgMPC

- Prohibitive overhead

Approach 2: Hardware enclaves

- Trusted code runs shielded from OS and processes on the same host
- Memory access pattern leakage



Access pattern leakage

Access patterns leak information such as filter selectivity

ID	Credit score	Loan amount
1	720	$2,500
2	600	$500
2	600	$250
3	600	$500

Total loans
$1,250

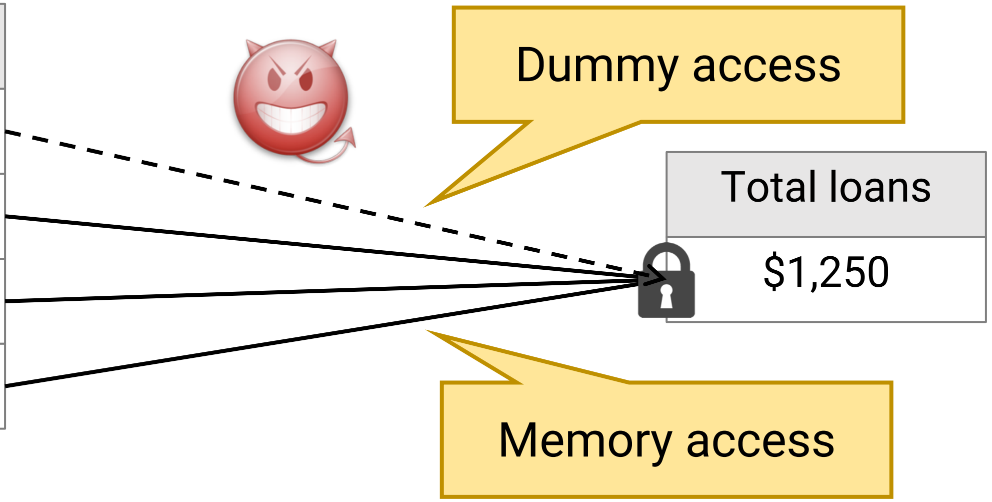
Memory access

```
SELECT SUM(loan_amount)
FROM customer c
  JOIN loan l ON c.ssn = l.ssn
WHERE credit_score < 630;
```

Oblivious algorithms

Oblivious algorithms hide access patterns at a performance cost

ID	Credit score	Loan amount
1	720	$2,500
2	600	$500
2	600	$250
3	600	$500




```sql
SELECT SUM(loan_amount)
FROM customer c
  JOIN loan l ON c.ssn = l.ssn
WHERE credit_score < 630;
```

Previous approaches using hardware enclaves

Not oblivious: SCONE, Graphene, Haven, VC3

- Side channel leakage

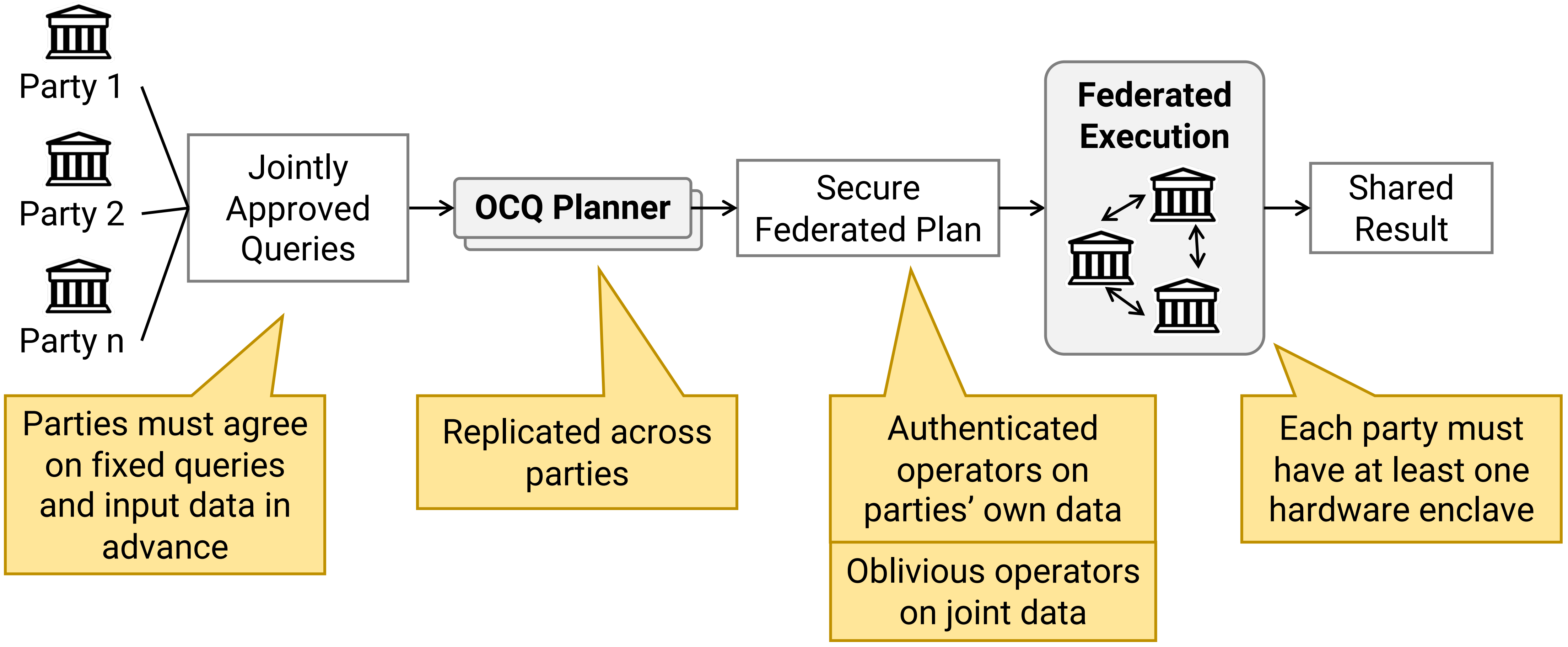
Oblivious: Cipherbase, Opaque

- Must maintain remote copy of large datasets; expensive to update
- If applied to WAN setting, inefficient due to high-bandwidth shuffles

Oblivious Coopetitive Queries (OCQ)

- Designed for oblivious coopetitive analytics
- Supports general SQL queries with better performance than previous approaches
- Protects against network attacker and malicious party attackers (in the hardware enclave model)

Oblivious Coopetitive Queries (OCQ)



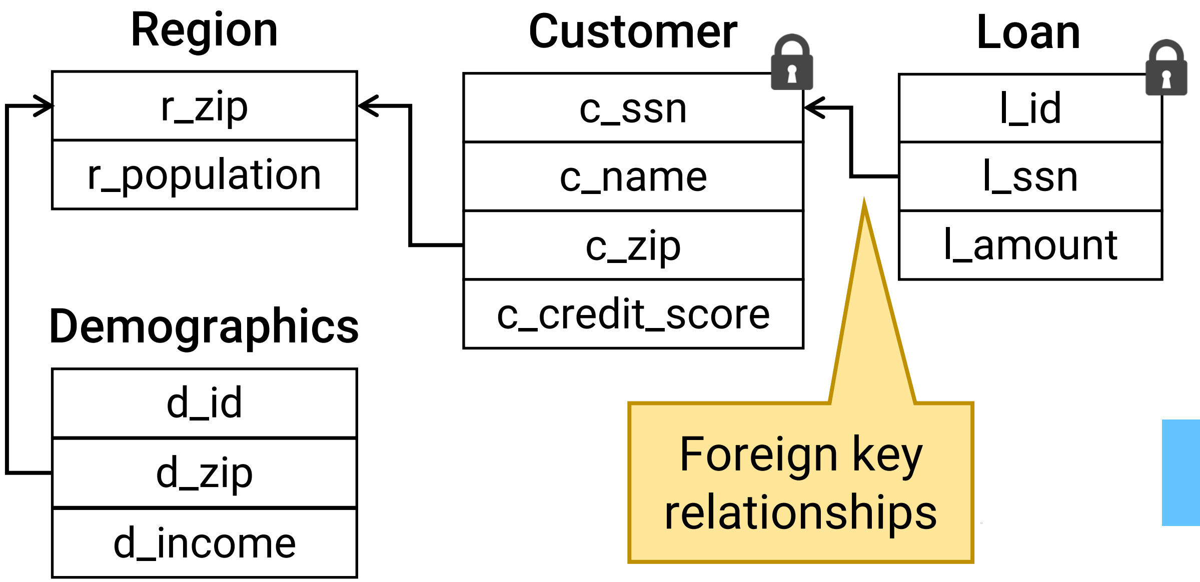
Challenges and Techniques

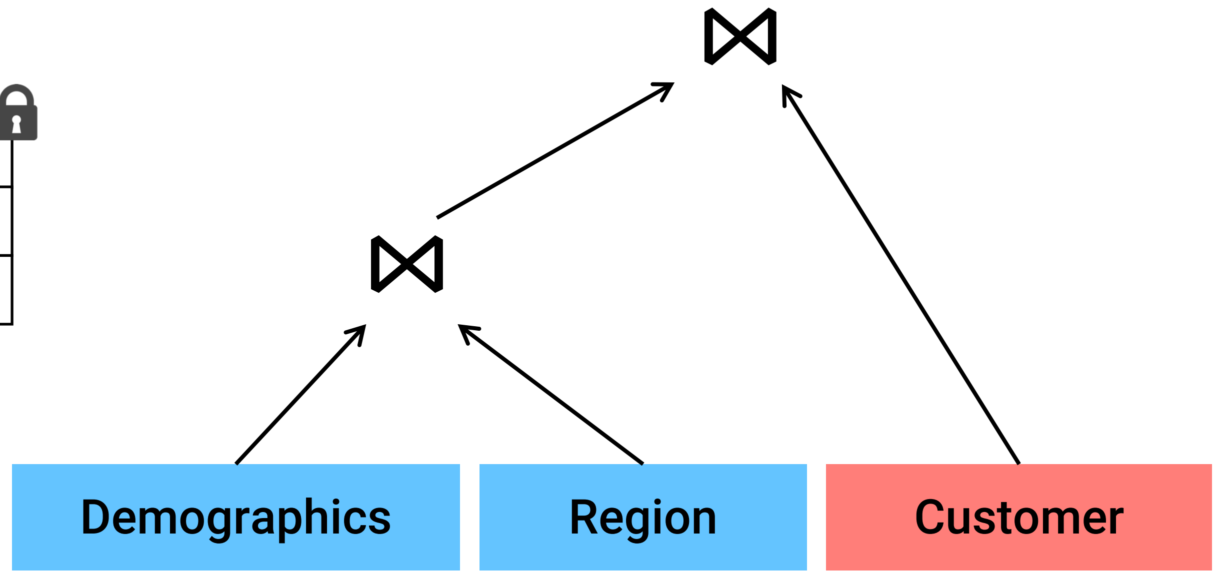
1. Combining data of mixed sensitivities
   → Approach: Mixed-sensitivity algorithms
2. Query planning with sensitive cardinalities
   → Approach: Schema-aware padding
3. Oblivious queries in the wide area
   → Federated- and security-aware planner

Sensitivity propagation

Parties specify sensitivity of each table: Public or Sensitive

Propagate sensitivity according to *foreign keys* and *operators*





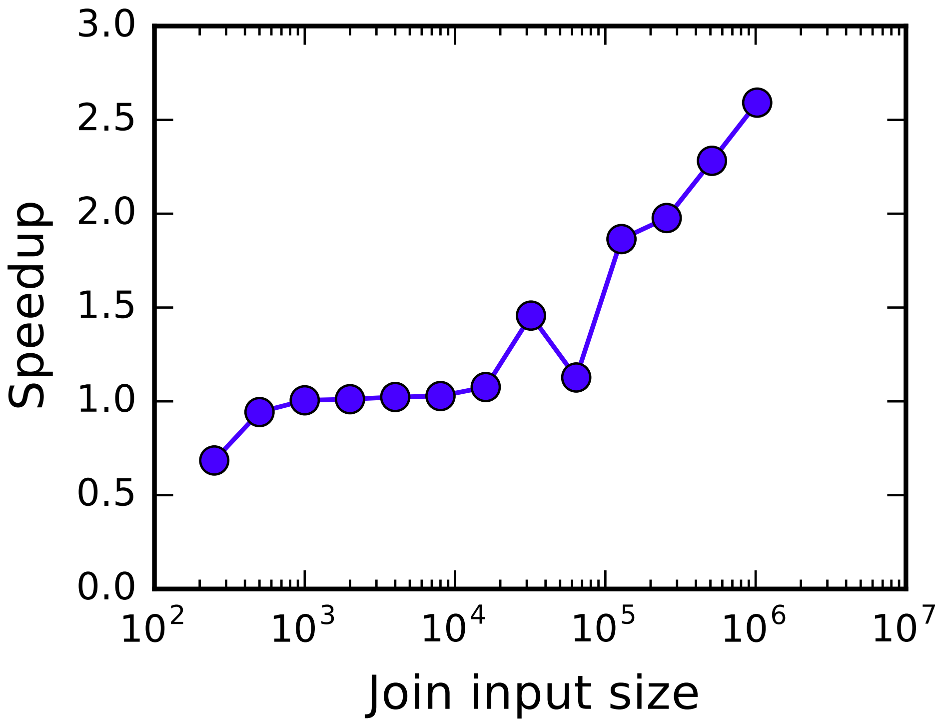
Mixed-sensitivity oblivious join

Joining Sensitive tables across parties produces a **mixed-sensitivity join**

Mixed-sensitivity oblivious join algorithm:

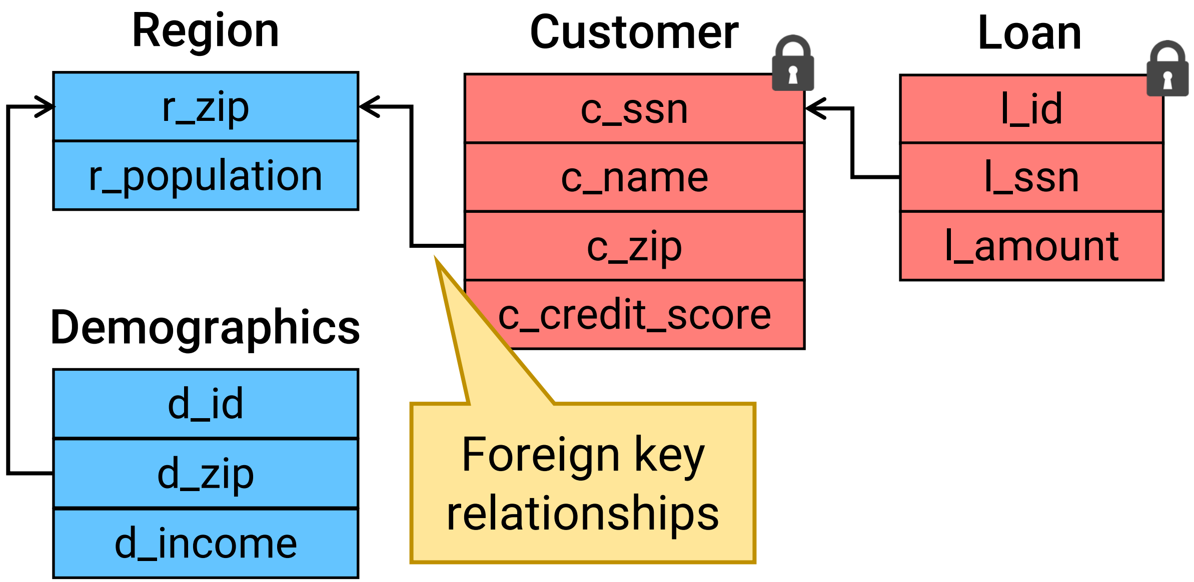
1. Sort Public and Sensitive sides separately
2. Oblivious bitonic merge join

Up to 2.5x speedup vs. fully-oblivious join for equal-sized tables



Schema-aware padding

- Cardinalities are particularly sensitive in the federated setting
- Naïve "filter push-up" approaches to padding are very expensive
- Find tighter padding bounds using foreign key constraints

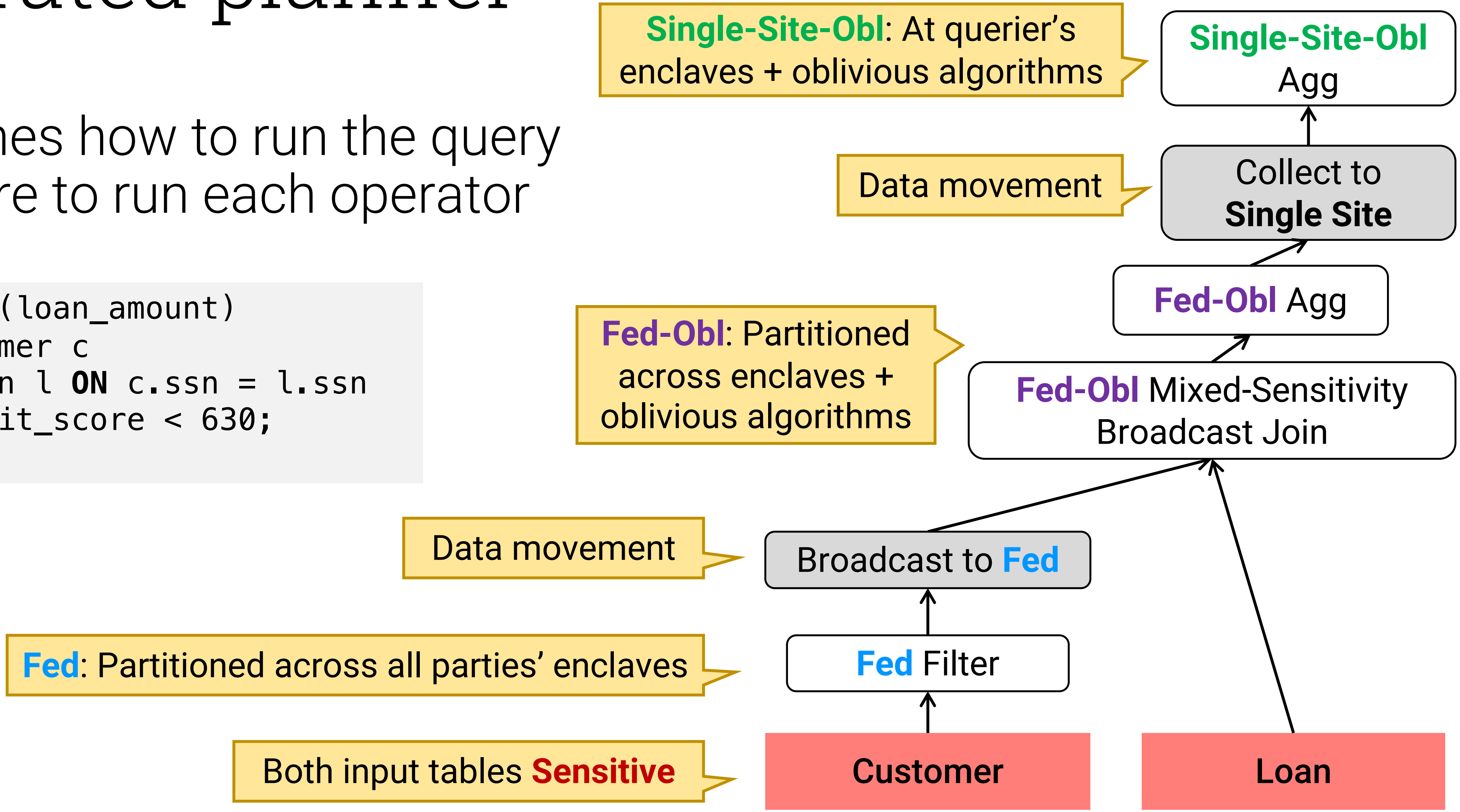



```
SELECT c_zip, AVG(l_amount / d_income)
FROM customer
  JOIN loan ON c_ssn = l_ssn
  JOIN region ON c_zip = r_zip
  JOIN demographics ON r_zip = d_zip
GROUP BY c_zip
```

Federated planner

Determines how to run the query and where to run each operator

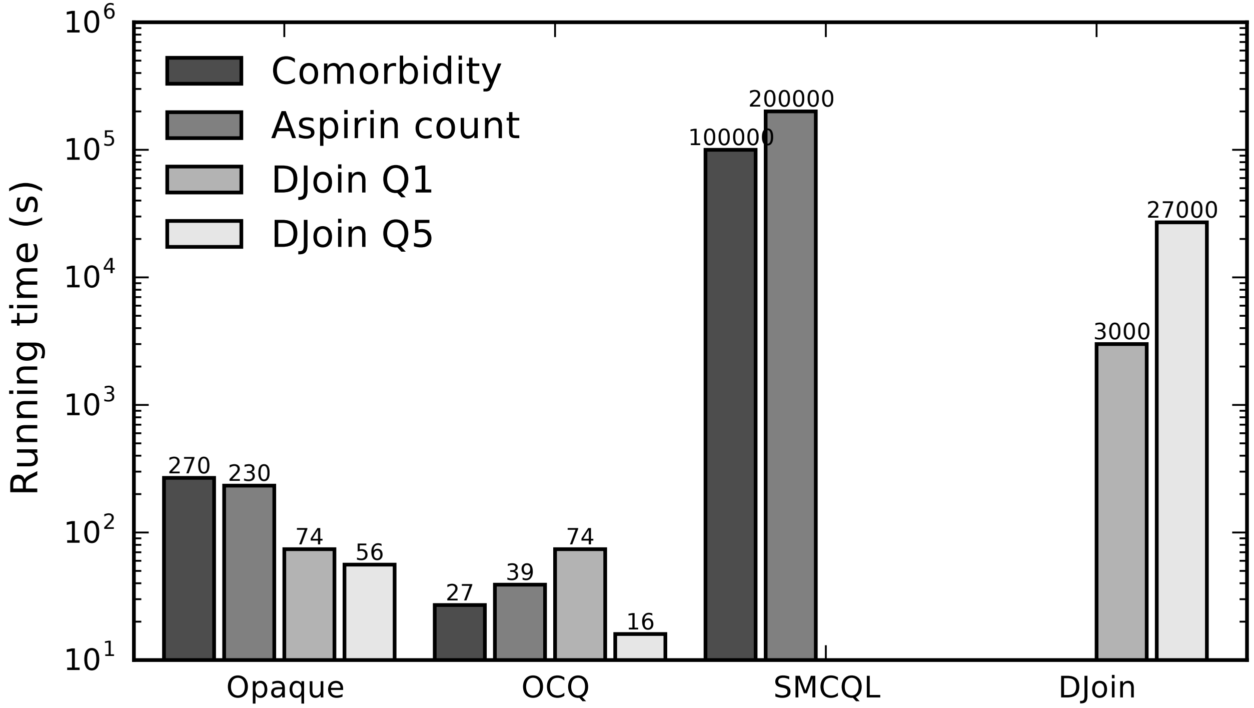
```sql
SELECT SUM(loan_amount)
FROM customer c
  JOIN loan l ON c.ssn = l.ssn
WHERE credit_score < 630;
```



Evaluation setup

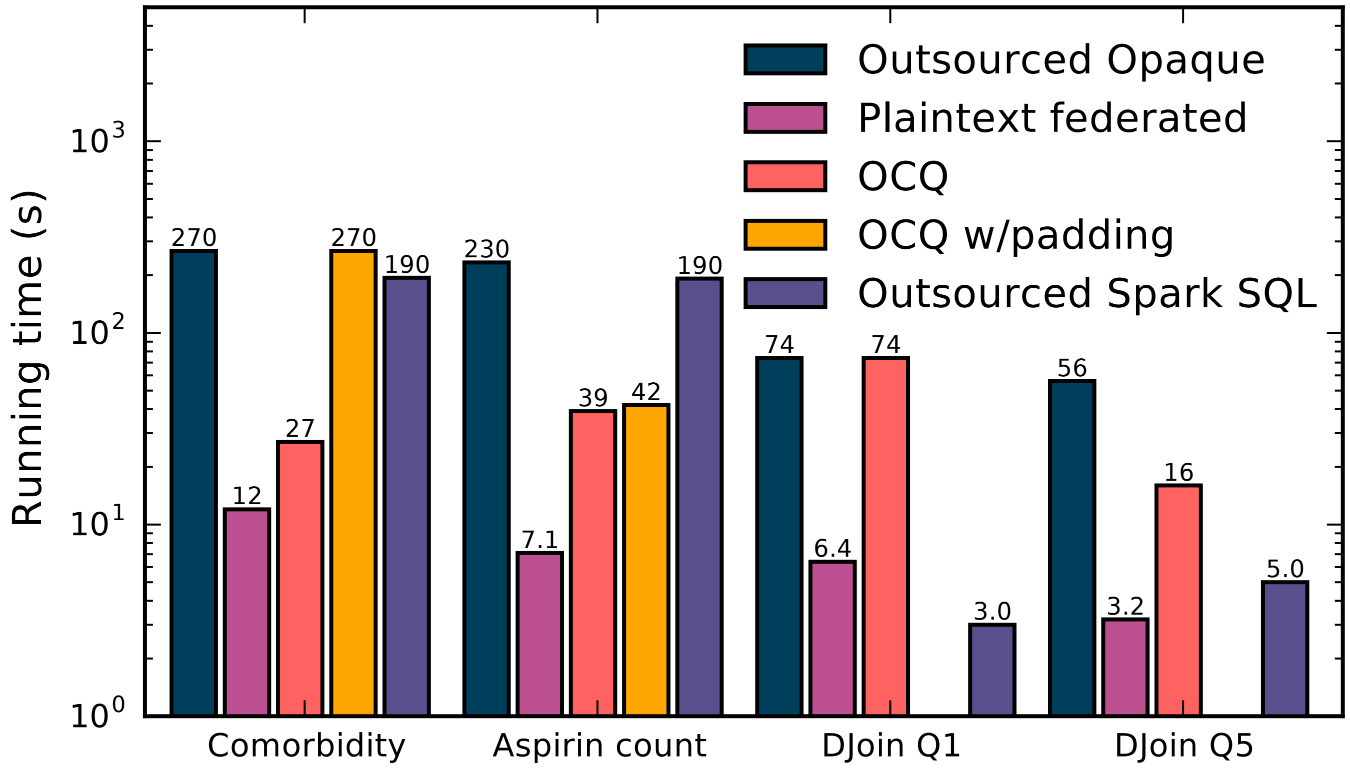
- 5 geo-distributed parties
- ~10 MB/s bandwidth
- Synthetic data, table sizes 4.3 MB–10 GB

OCQ vs. prior work



- Orders of magnitude faster than SMCQL and DJoin due to trusted hardware
- Faster than Opaque because OCQ can execute initial filters in plaintext

Overhead of OCQ’s security



- 2.2–25x overhead vs. insecure federated or outsourced Spark SQL

Summary of OCQ's contributions

Efficient, general framework for oblivious coopetitive analytics

1. Mixed-sensitivity oblivious join and aggregation algorithms
2. Schema-aware padding
3. Secure coopetitive query planner