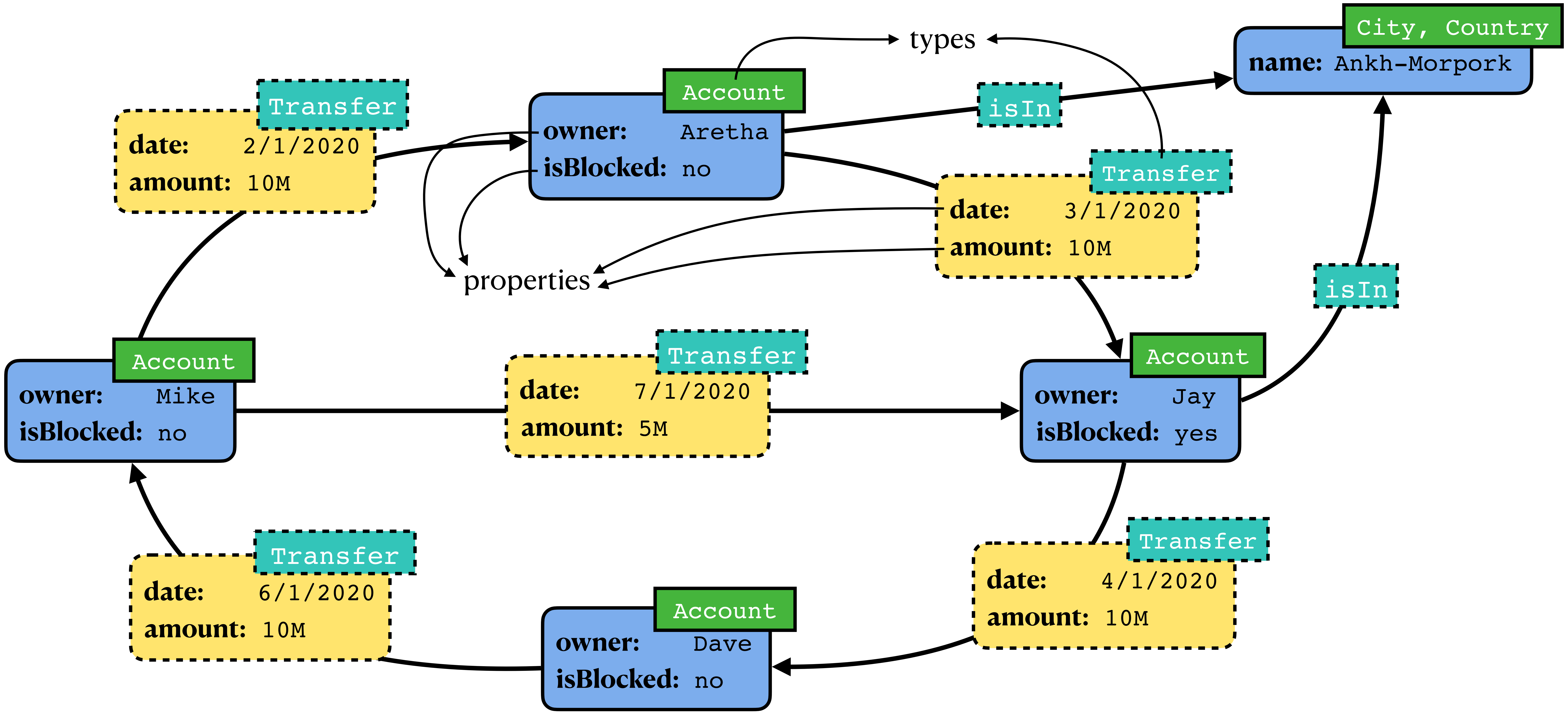
# Graph Pattern Matching in GQL and SQL/PGQ

SIGMOD 2022 (Industry Paper) + LDBC Presentation

# Property Graphs

- A data model based on graphs where both nodes and relationships can have properties (attributes) and types (label)



# Property Graphs in Industry

- Multiple vendors:
  - Neo4j
  - Oracle
  - TigerGraph
  - Amazon
  - SAP
  - Redis
  - DataStax, etc.
- Widespread: used by 75% of Fortune 100 companies
- Prediction (Gartner): in the next 5 years, up to **80% of all data analytics** tasks will involve graph databases
- Prediction (IDG): Graph database market will experience **600% growth** over the next decade

# Querying Property Graphs

- Multiple declarative languages: Cypher, PGQL, GSQL, G-Core, etc…
  - They look like dialects of the same language rather then different ones
- New Standard: **GQL (Graph Query Language)**
  - in development since 2019
- Another standardization project: **SQL/PGQ** (SQL Property Graph Querying):
  - graphs are defined as views over a relational schema
  - in development since 2017
- The engine of a graph query language: **graph pattern matching language (GPML)**
  - shared by GQL and SQL/PGQ

# Standards: Process

**ISO/IEC JTC1 SC32 WG3**

SQL Standard Committee:
9075-16 - SQL/PGQ
39075 - GQL Standard

**Linked Data Benchmark Council**

Liaison

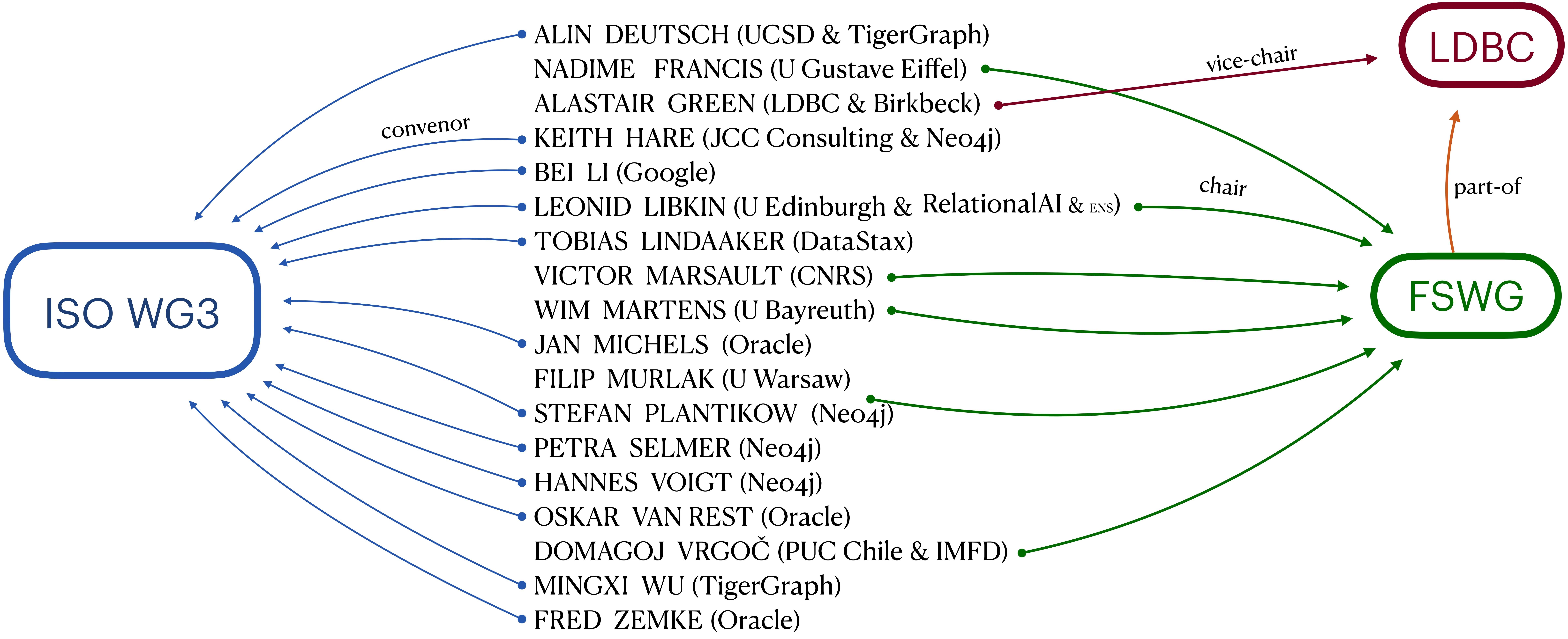
LDBC

Working groups

Formal Semantics Working Group (FSWG)

analyzes design decisions;
provides feedback

# Authors



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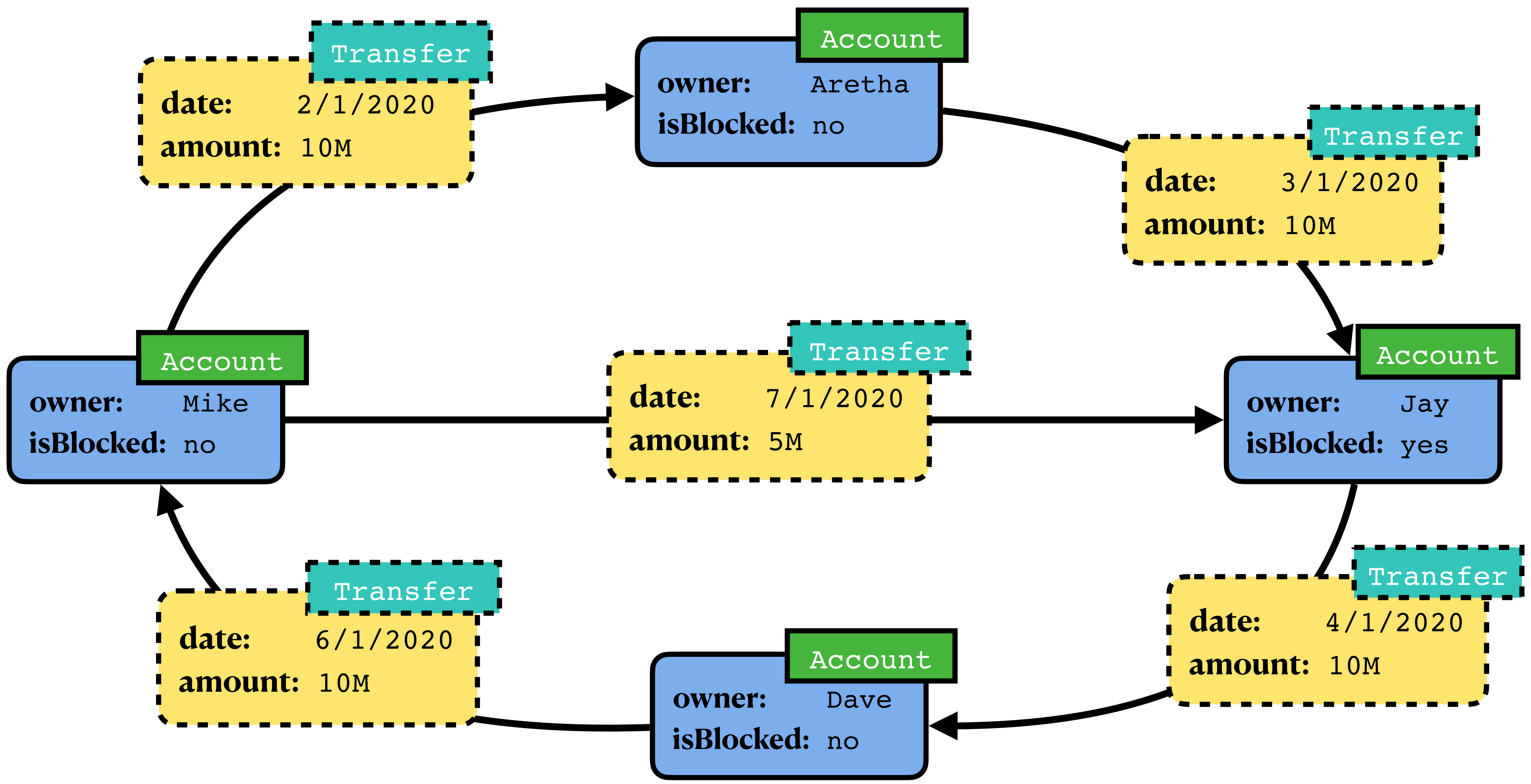
# GPML: Nodes

Selecting nodes:

```
MATCH (x:Account)
WHERE x.isBlocked = 'no'
```



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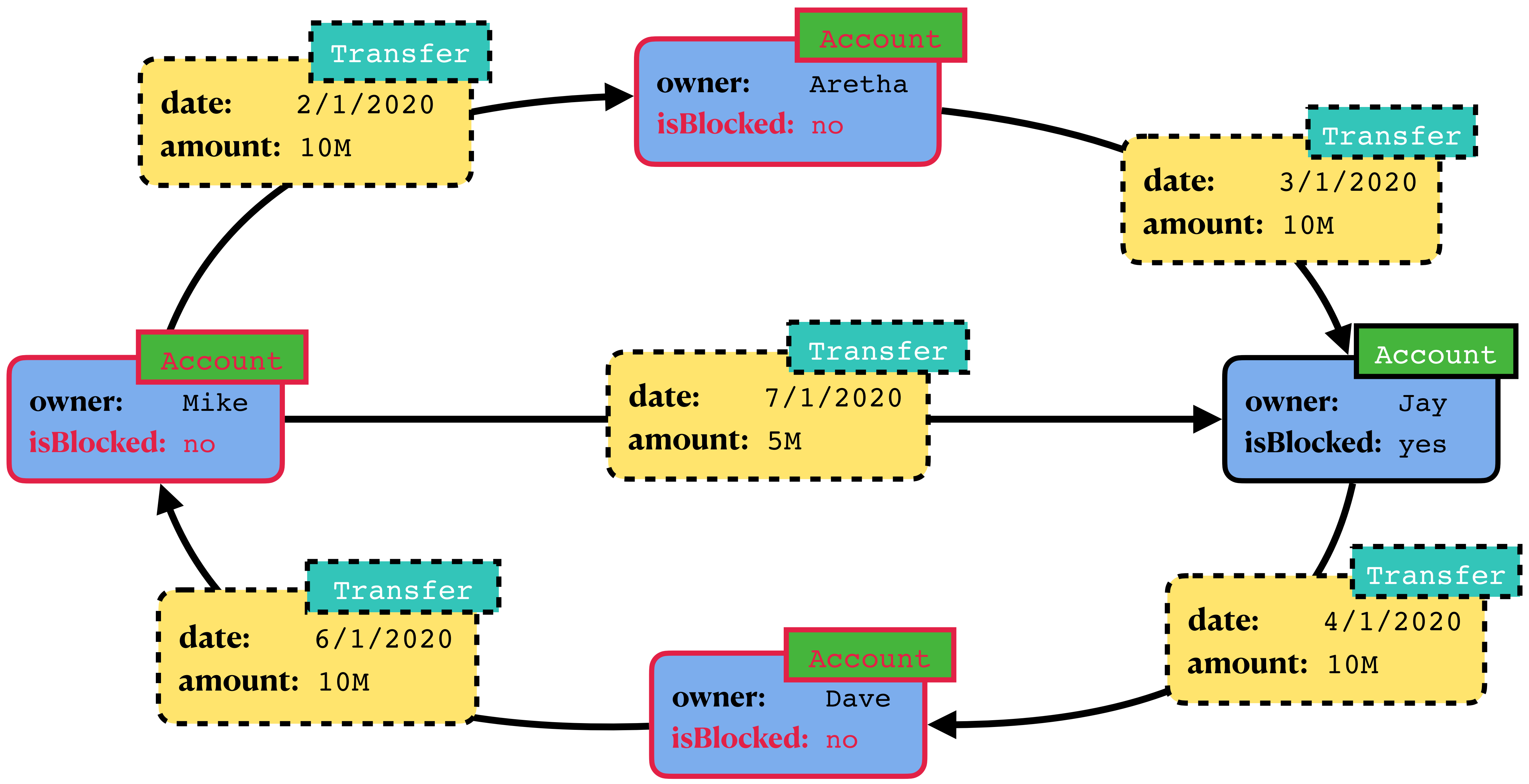
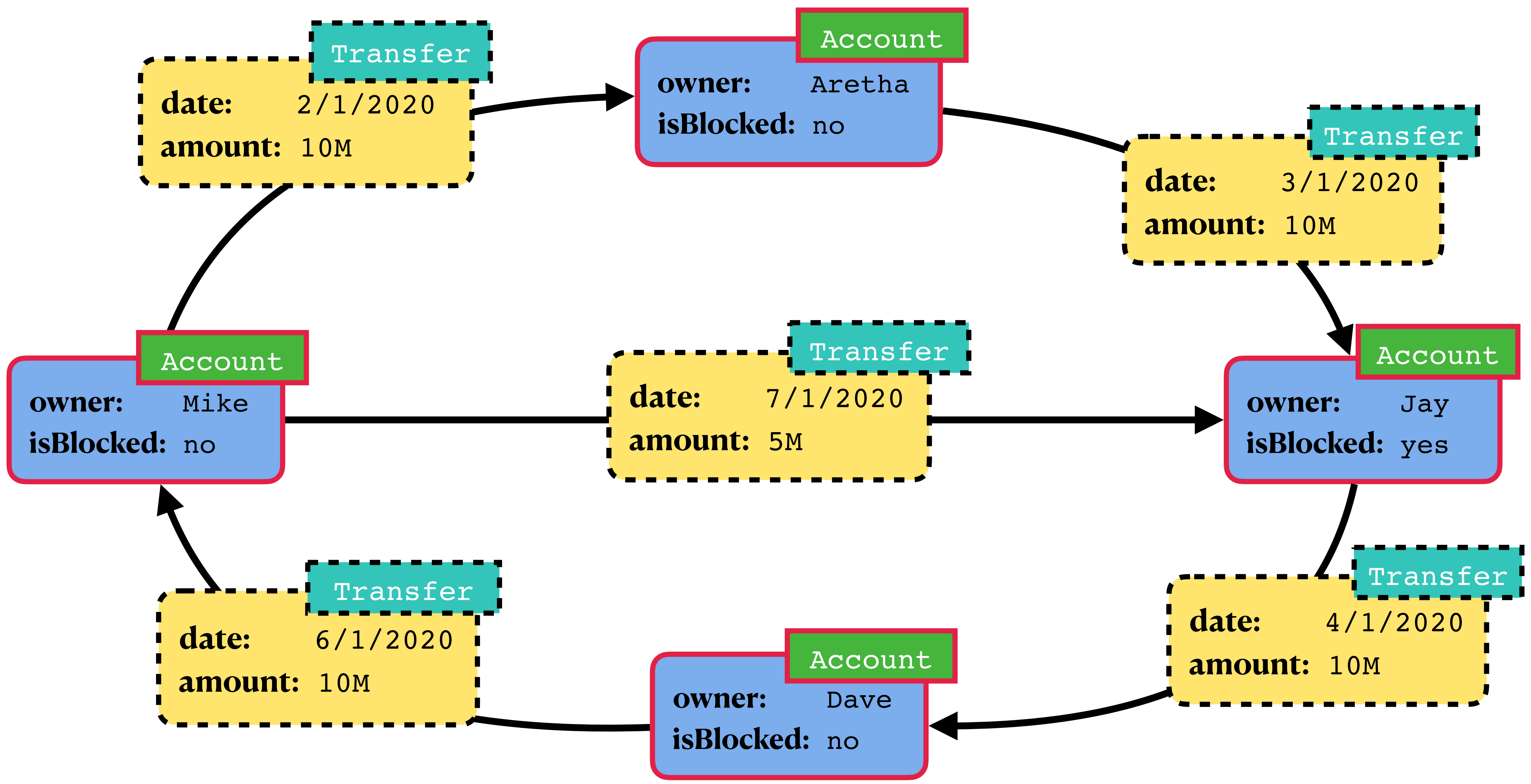


# GPML: Nodes

All nodes:

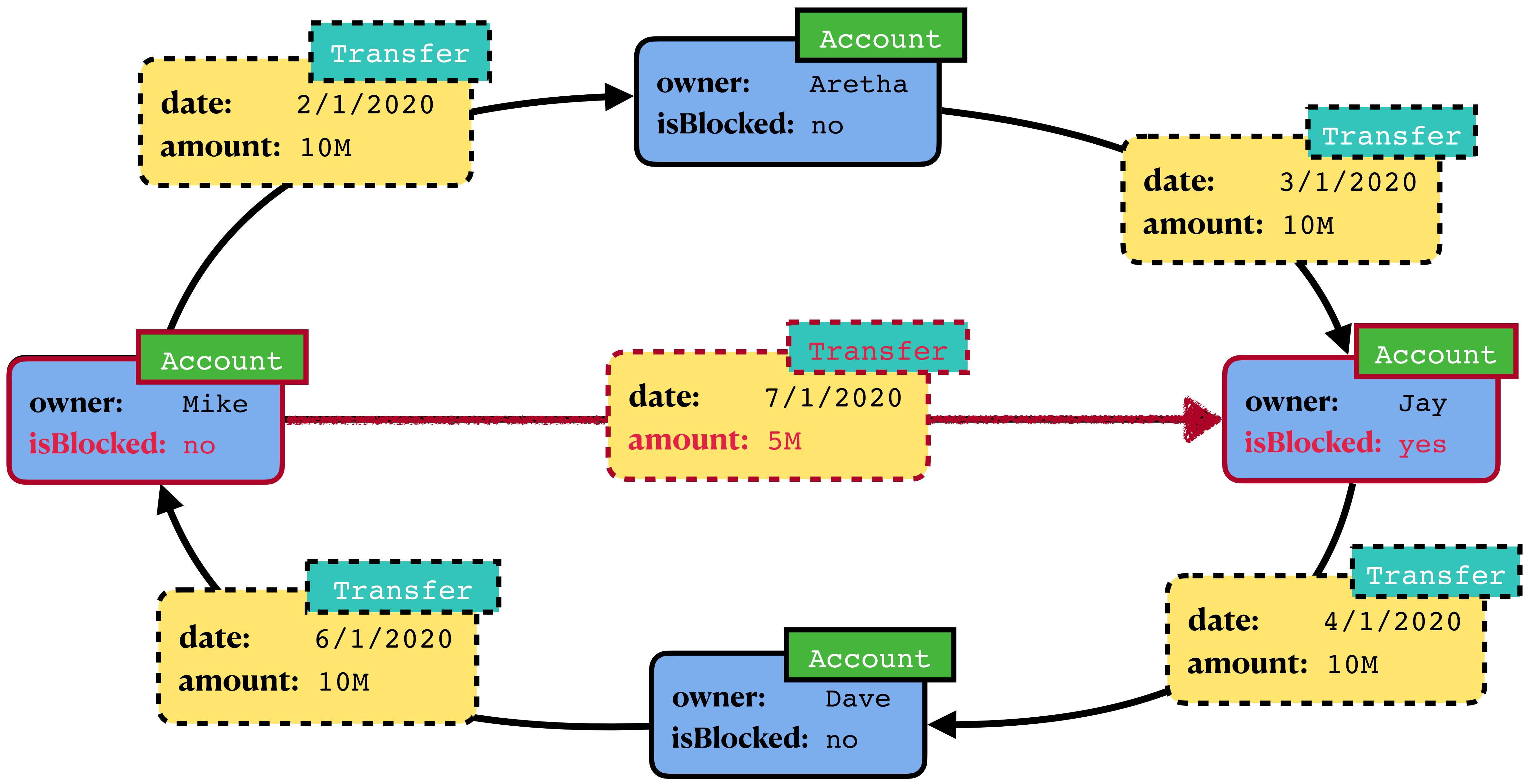
```
MATCH (x)
```



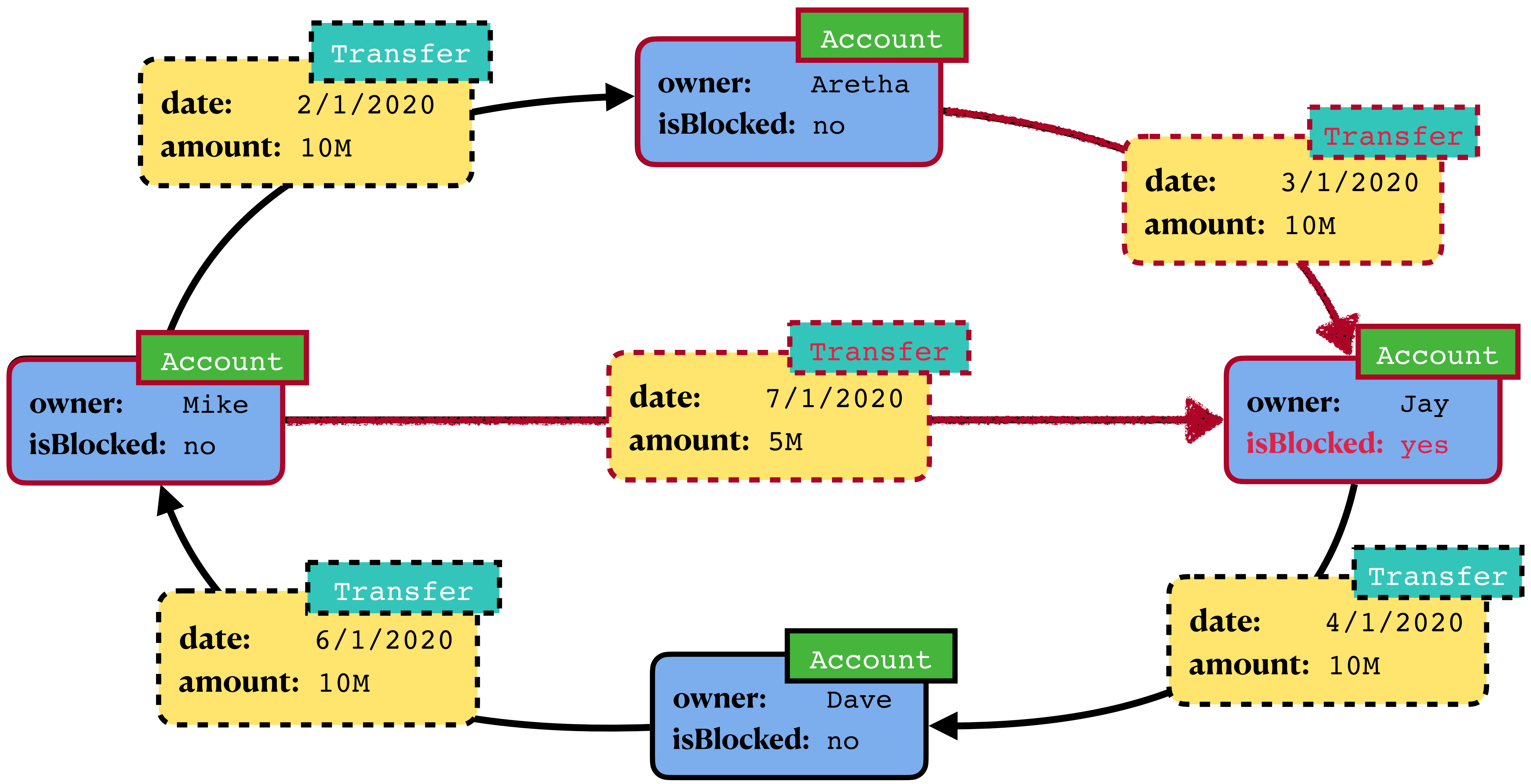
# GPML: Paths

Combining nodes and edges:

```
MATCH (x)-[e1:Transfer]->(y)
WHERE x.isBlocked = 'no'
  AND y.isBlocked = 'yes'
  AND e1.amount <= 5M
```



# GPML: Paths

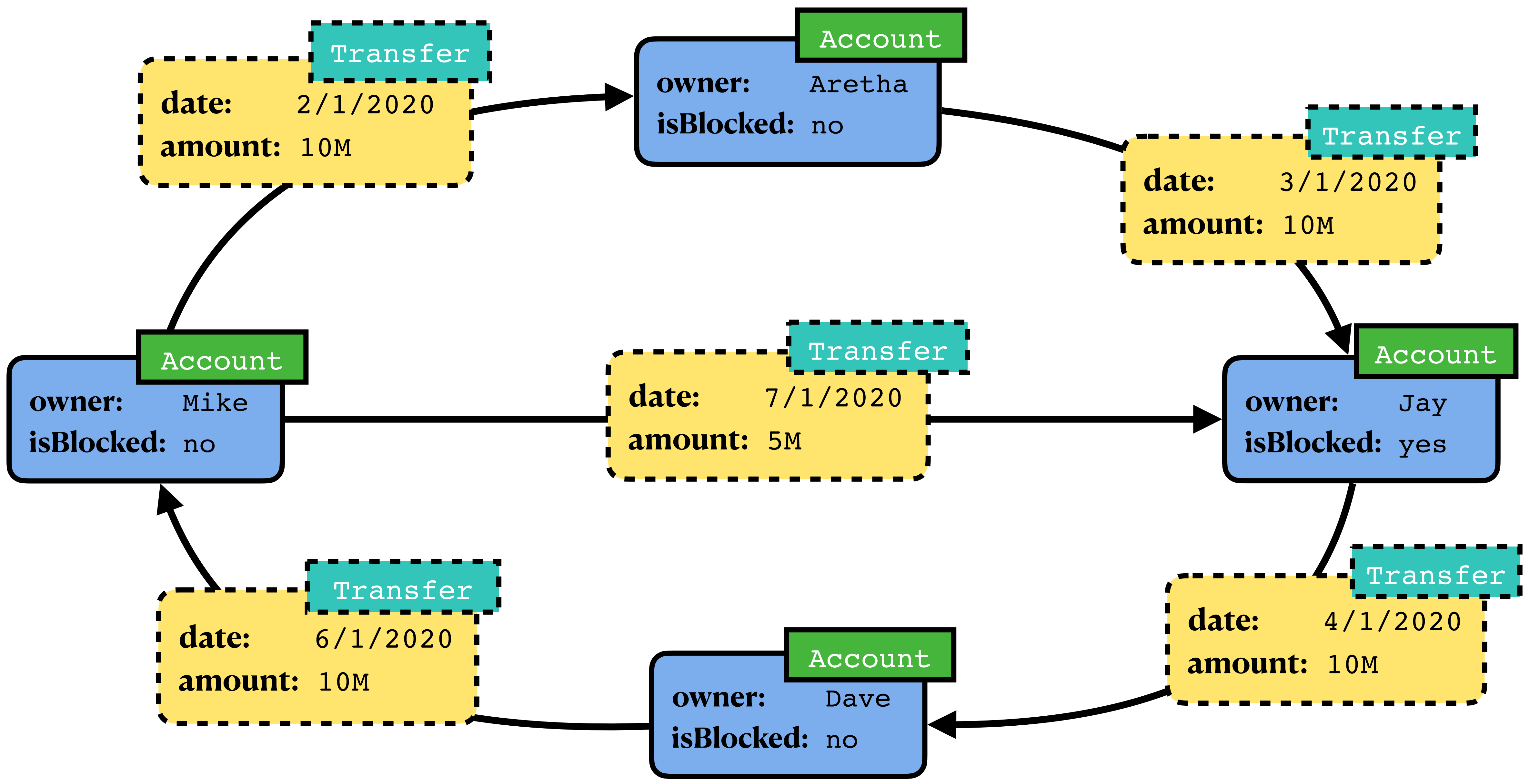



Multiple edge options: ~, -, ->, <-

Longer paths are defined via ASCII art:

```
MATCH (x)-[:Transfer]->(y)<-[:Transfer]-(z)
WHERE y.isBlocked = 'yes'
```

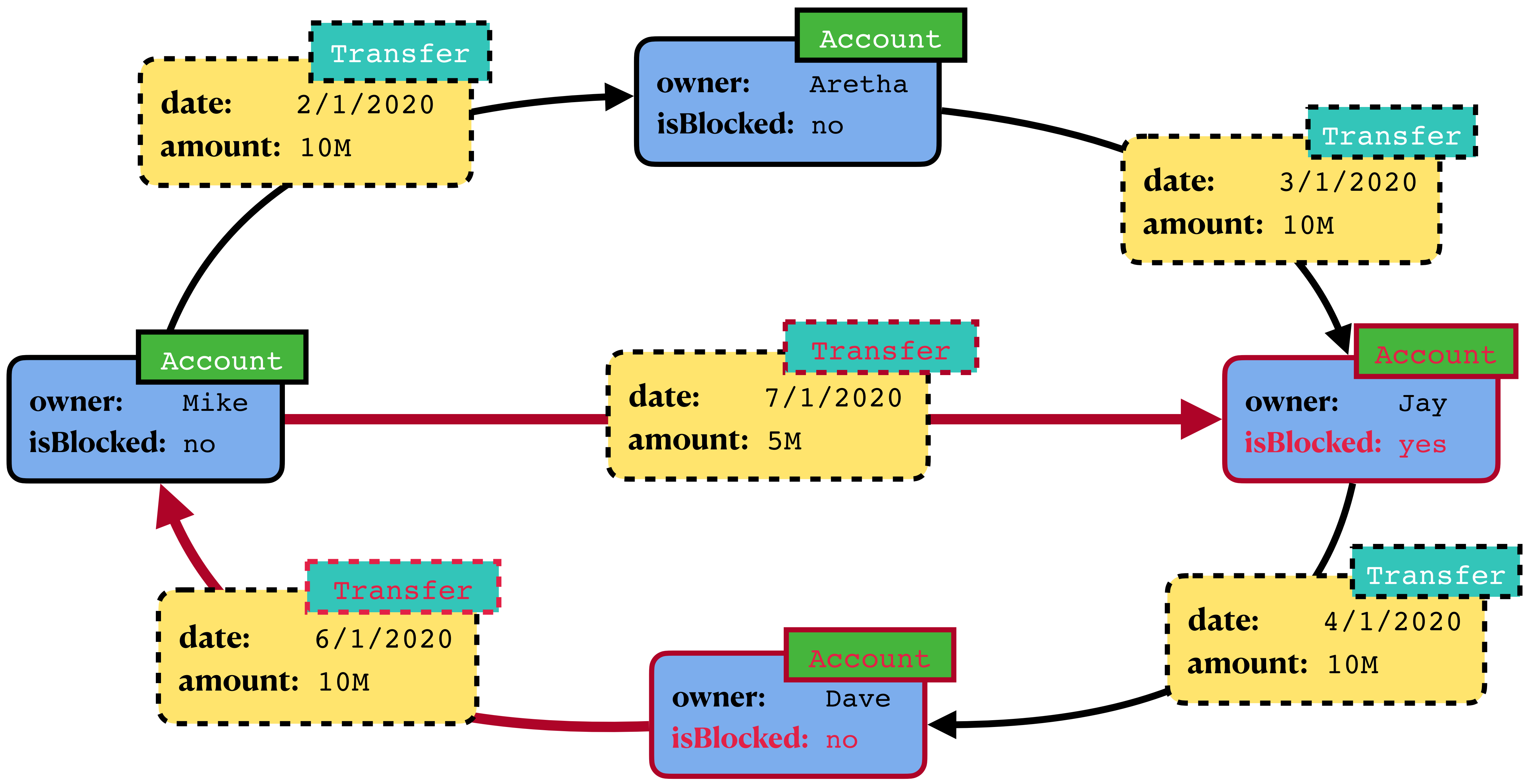
# GPML: Path traversal




Specifying graph traversal:

```
MATCH (x:Account)-[t:Transfer]->{2,5}(y:Account)
WHERE x.isBlocked = 'no' AND y.isBlocked = 'yes'
```

# GPML: Path traversal

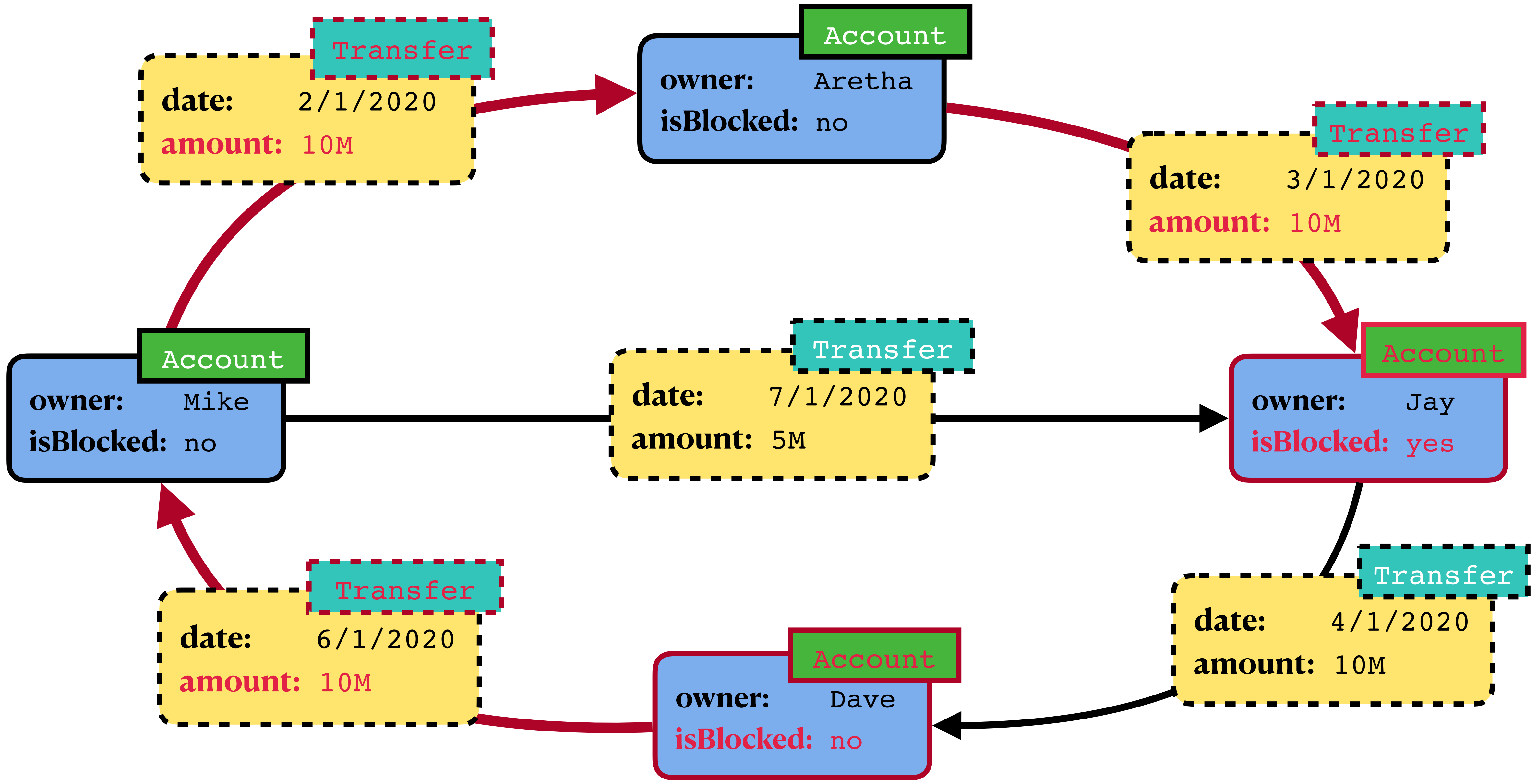



Specifying graph traversal:

```
MATCH (x:Account)-[t:Transfer]->{2,5}(y:Account)
WHERE x.isBlocked = 'no' AND y.isBlocked = 'yes'
```

# GPML: Path traversal

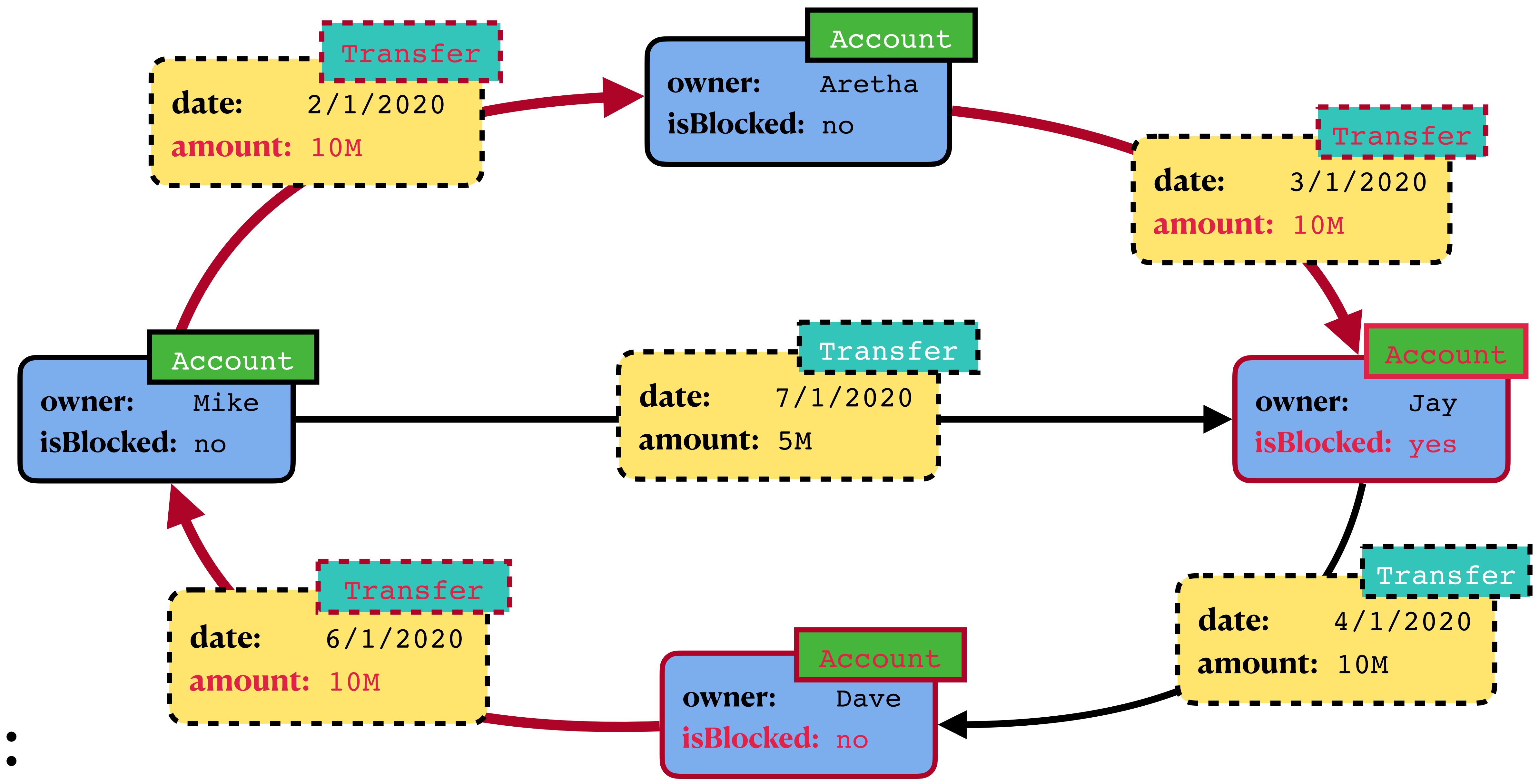
Allowed quantifiers: `{m,n}`, `*`, `+`




Path conditions can be added:

```
MATCH (x:Account)
      -[t:Transfer WHERE t.amount > 7M]->{2,5}
      (y:Account)
WHERE x.isBlocked = 'no' AND y.isBlocked = 'yes'
```

# GPML: Path traversal



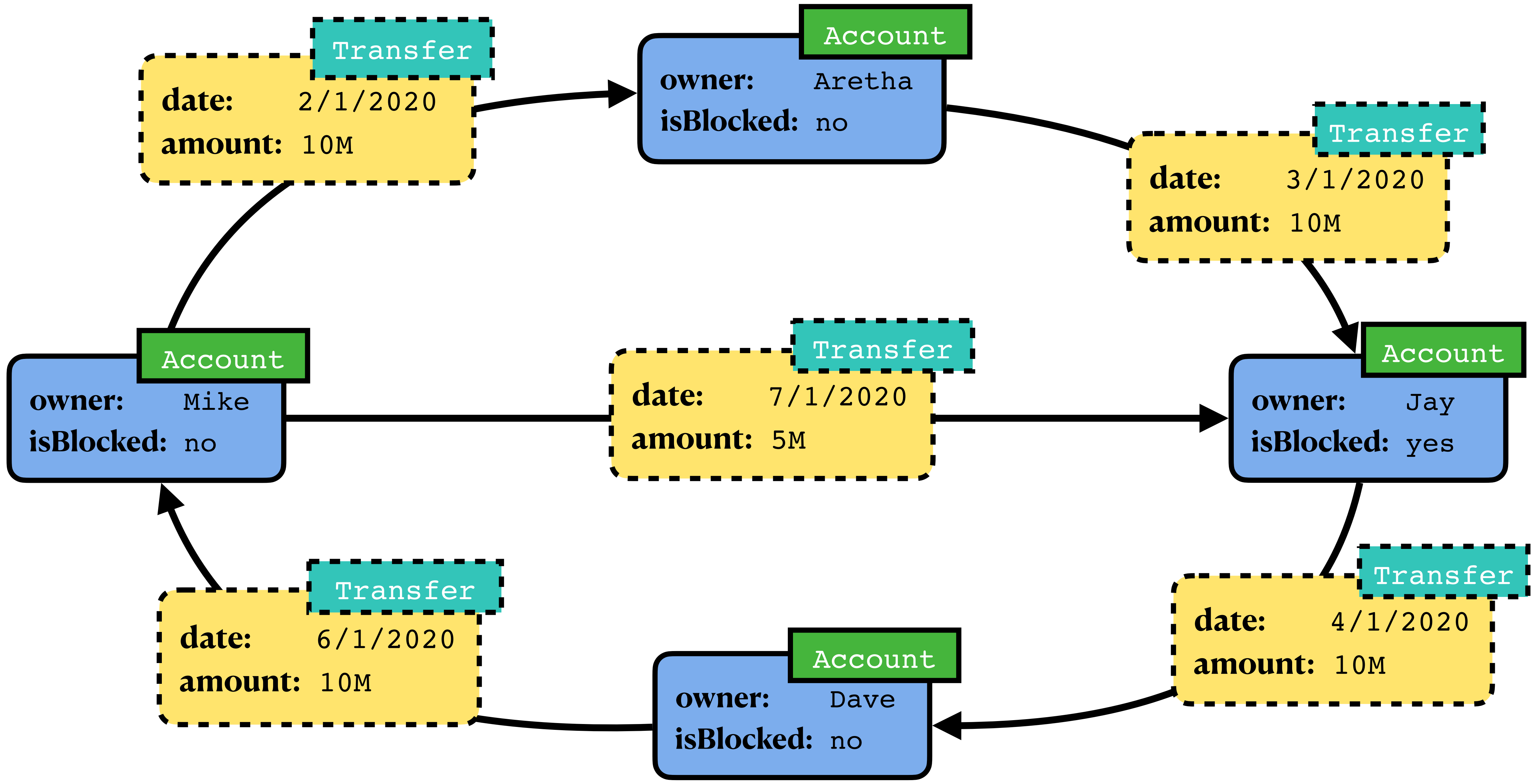

It's not just single edges that can be repeated:

```
MATCH (x:Account)
      [ -[t:Transfer WHERE t.amount > 7M]->
        [t1: Transfer WHERE t1.amount > 3M] -> ]{2,5}
      (y:Account)
WHERE x.isBlocked = 'no' AND y.isBlocked = 'yes'
```

# GPML: Simple, Trail, Shortest

Issues when returning paths:

```
MATCH
    p = (x WHERE x.owner = 'Mike')
            -[:Transfer]->*
        (y WHERE y.owner = 'Jay')
```



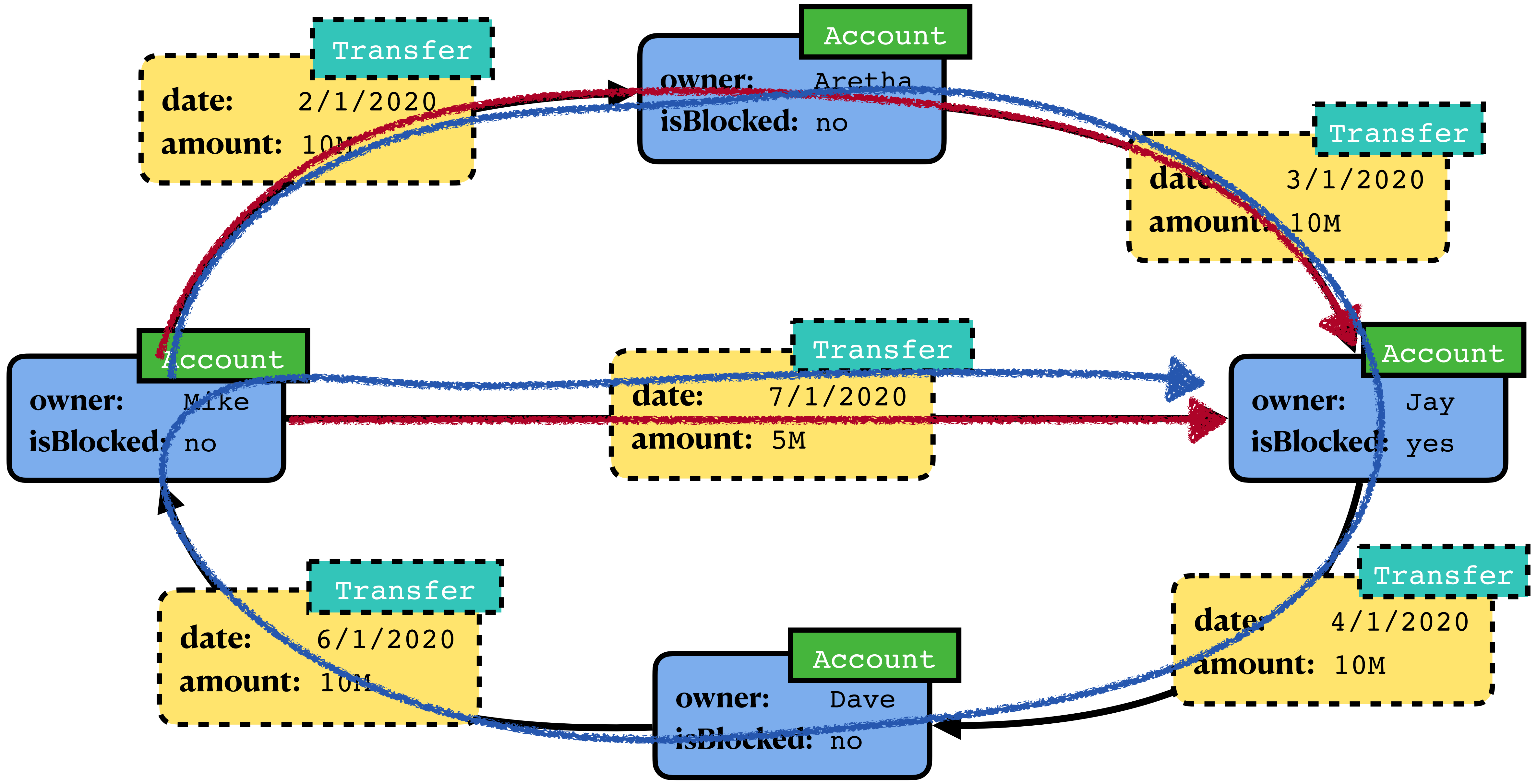

To deal with this GPML allows restrictors and selectors:

- **restrictors** restrict the set of considered paths to be finite;
- **selectors** filter out the results to assure finiteness.

# GPML: Simple, Trail, Shortest

How do **restrictors** work?

```
MATCH SIMPLE
    p = (x WHERE x.owner = 'Mike')
              -[:Transfer]->*
        (y WHERE y.owner = 'Jay')
```

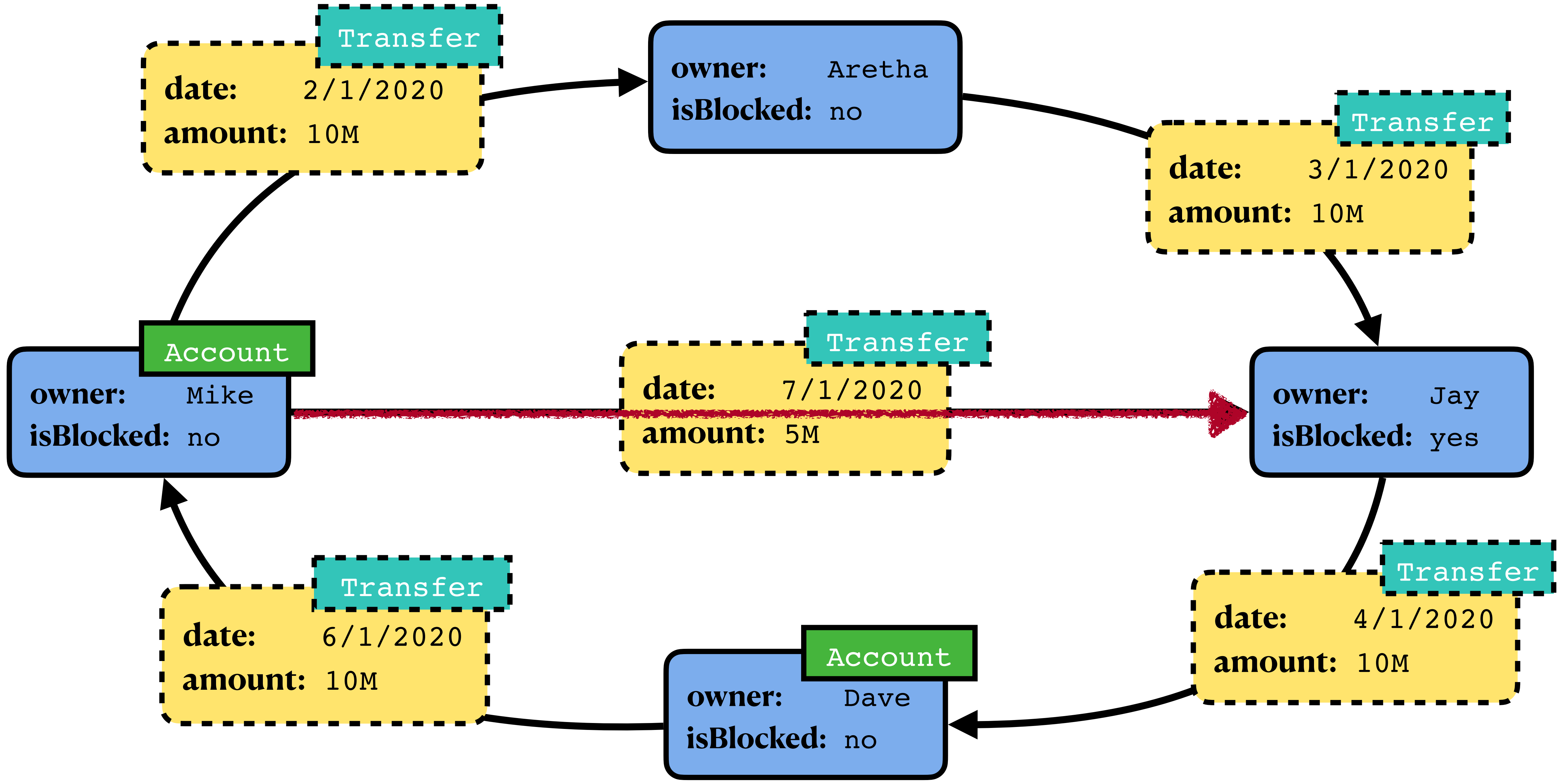



Also available: **`TRAIL`**, **`ACYCLIC`**

# GPML: Simple, Trail, Shortest

How **selectors** work?

```
MATCH ALL SHORTEST
    p = (x WHERE x.owner = 'Mike')
            -[:Transfer]->*
        (y WHERE y.owner = 'Jay')
```




Also available: **`ANY SHORTEST`**

Can be combined with restrictors

# GPML: Union, Optional

Two types of union: set-based and multiset-based (SQL `UNION` vs `UNION ALL`)

Conditional matches:

```
MATCH (x)-[:Transfer]->(y)[-[:Transfer]->(z)]?
WHERE y.isBlocked = 'yes'
```

*Transfers to a blocked account, and, if available, all outgoing transfers.*

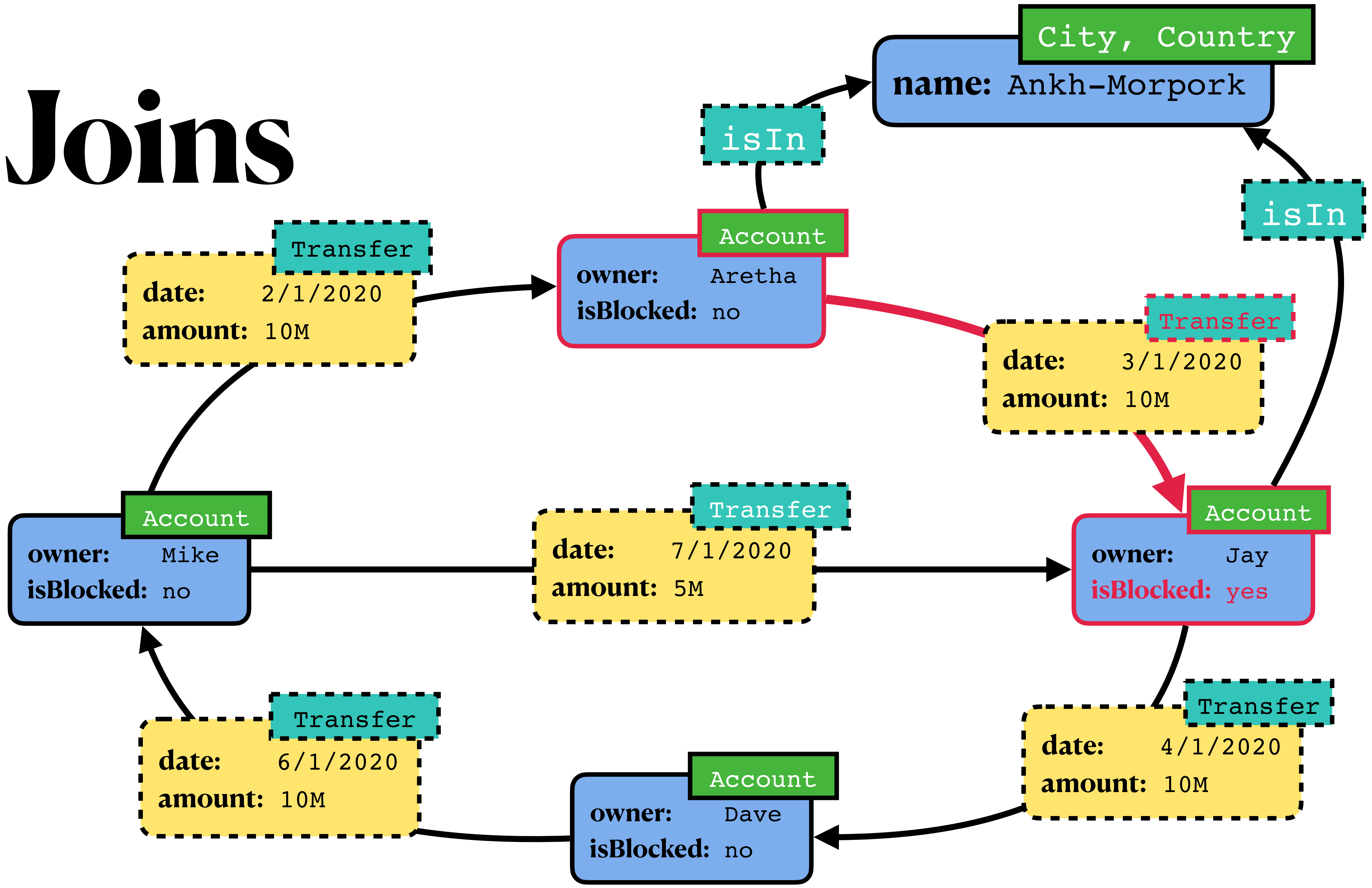
# GPML: Joins

Finally, we can combine all these into a single query:

```
MATCH TRAIL p = (x) -[:Transfer]->  (y),
                (y) -[:Transfer]->+ (x),
                (x:Account)-[:isIn]->(c1:City),
                (y:Account)-[:isIn]->(c2:City)
WHERE c1.name = c2.name AND y.isBlocked = 'yes'
```

*Accounts in the same city, with both a direct transfer between them, and also a path that links them in the other direction (i.e. Aretha is laundering money).*

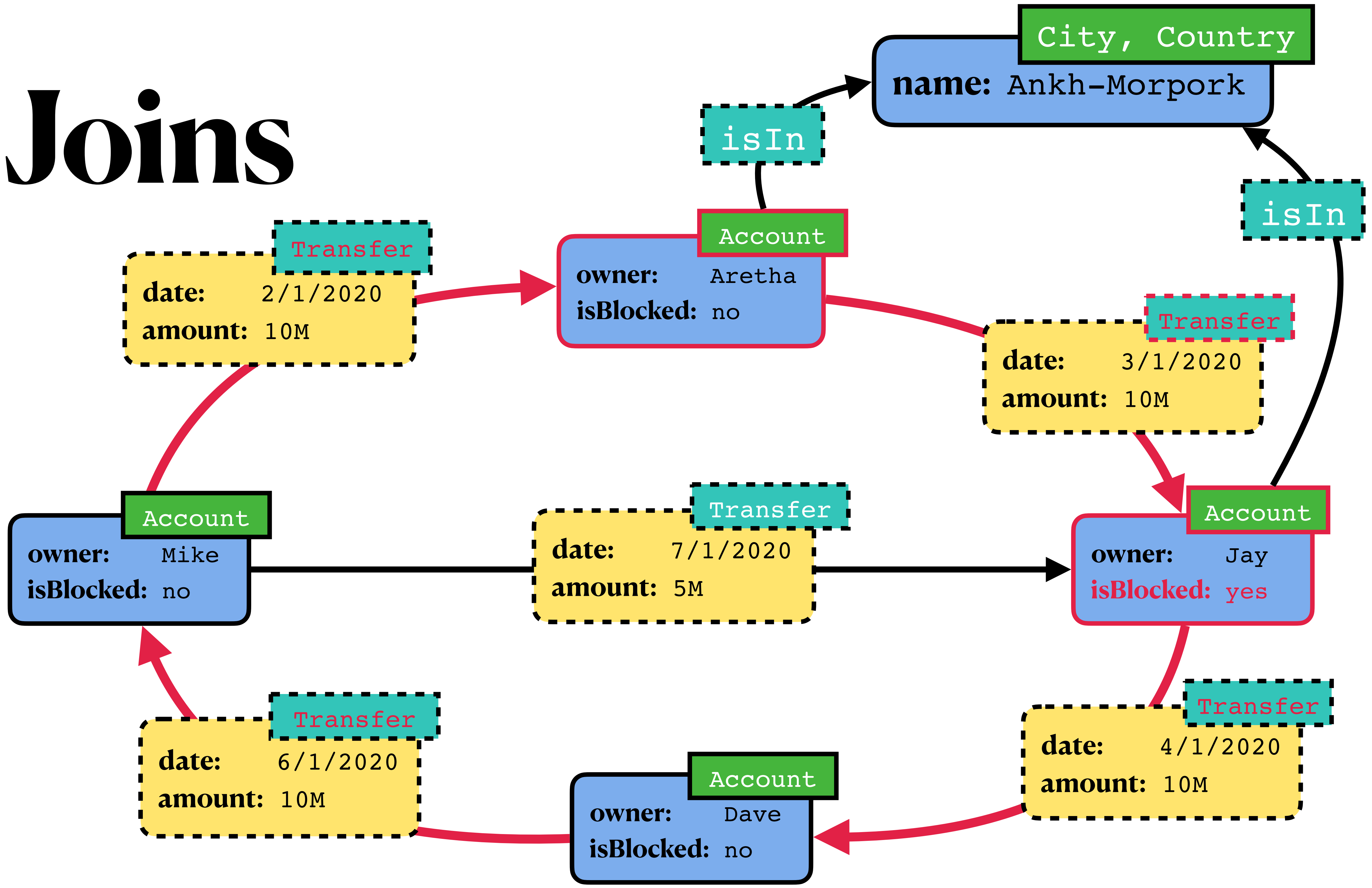
# GPML: Joins




Money laundering scheme:

```
MATCH TRAIL p = (x) -[:Transfer]->  (y),
                (y) -[:Transfer]->+ (x),
                (x:Account)-[:isIn]->(c1:City),
                (y:Account)-[:isIn]->(c2:City)
WHERE c1.name = c2.name AND y.isBlocked = 'yes'
```

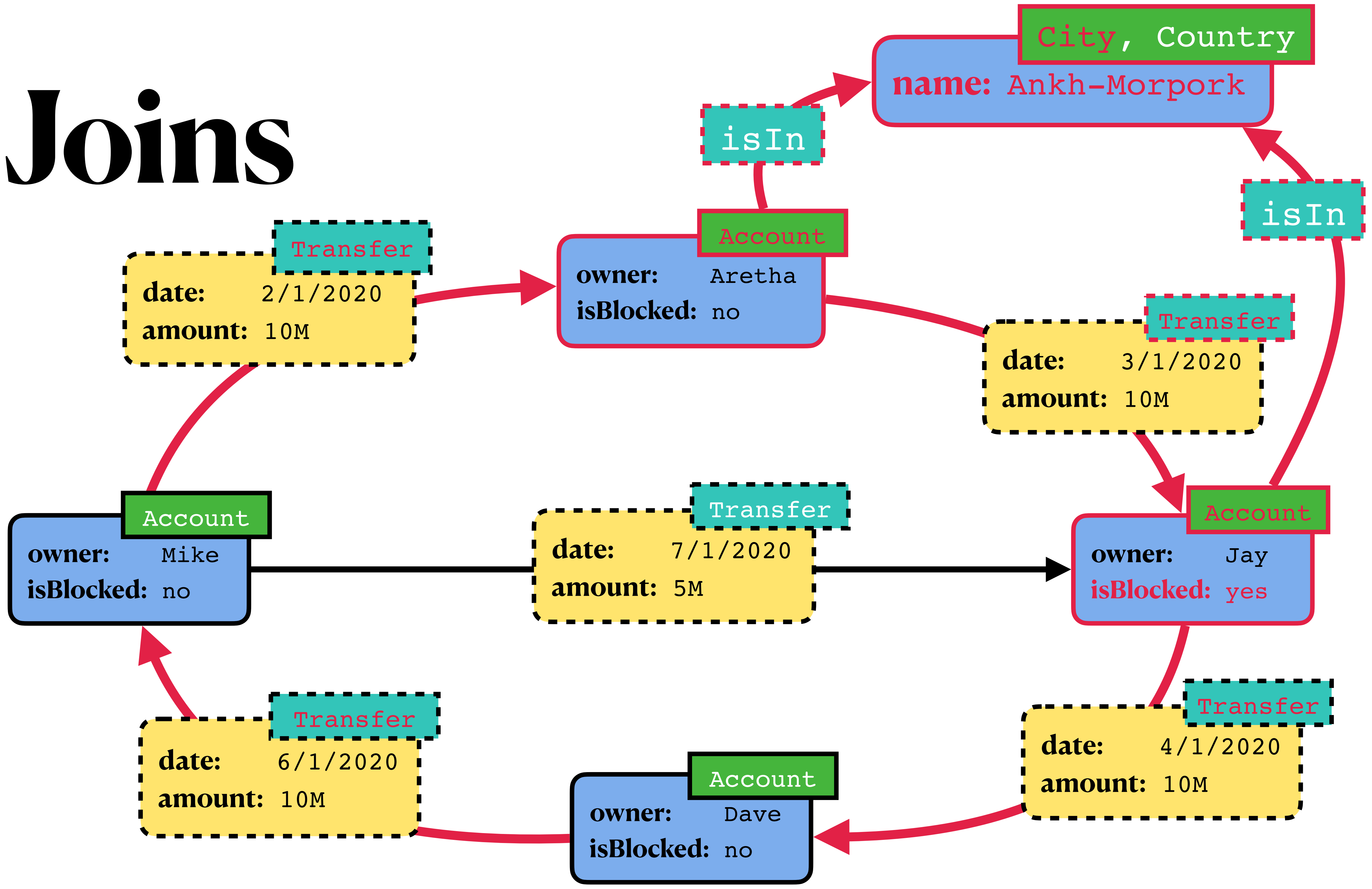
# GPML: Joins




Money laundering scheme:

```
MATCH TRAIL p = (x) -[:Transfer]->  (y),
                (y) -[:Transfer]->+ (x),
                (x:Account)-[:isIn]->(c1:City),
                (y:Account)-[:isIn]->(c2:City)
WHERE c1.name = c2.name AND y.isBlocked = 'yes'
```

# GPML: Joins



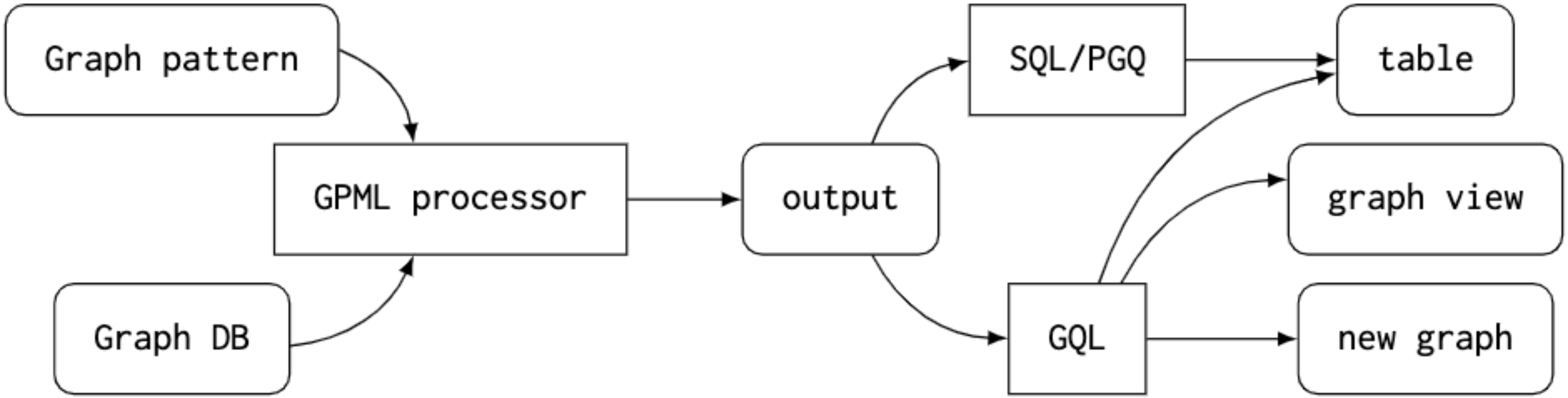

Money laundering scheme:

```
MATCH TRAIL p = (x) -[:Transfer]->  (y),
                (y) -[:Transfer]->+ (x),
                (x:Account)-[:isIn]->(c1:City),
                (y:Account)-[:isIn]->(c2:City)
WHERE c1.name = c2.name AND y.isBlocked = 'yes'
```

# GPML: Output

GPML output: a data structure that combines paths in graphs with bindings of variables

Can be embedded in GQL and in SQL/PGQ.



# Timeline to Standards

| Date | SQL/PGQ | GQL |
|---|---|---|
| 2017 | Work started | |
| 2018 | | Work started |
| 2021-02-07 | CD Ballot End | |
| 2022-02-20 | | CD Ballot End |
| 2022-12-04 | DIS Ballot End | |
| 2023-01-30 | Final Text to ISO | |
| 2023-03-13 | **SQL/PGQ IS Published** | |
| 2023-05-21 | | DIS Ballot End |
| 2023-07-30 | | Final Text to ISO |
| 2023-09-10 | | **GQL IS Published** |

# Research Challenges

- Find a workable abstraction of GPML for research (systems and theory).
- Support aggregation

```
MATCH (x)-[e:Flight]->*(y)
WHERE x.name='Zembla'
  AND y.name='Ankh-Morpork'
  AND SUM(e.duration) < 24
```

- Optimize GMPL processing (vendors already working on it).