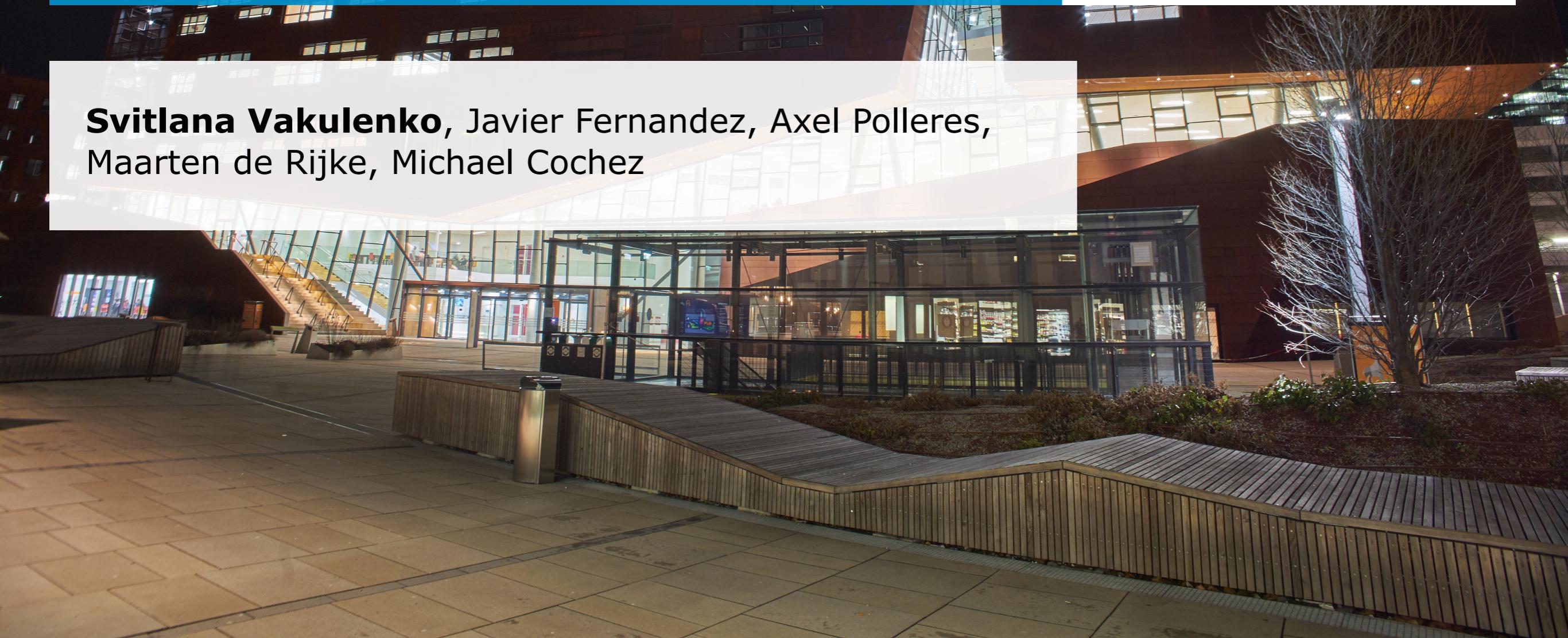


Message Passing for Complex Question Answering over Knowledge Graphs

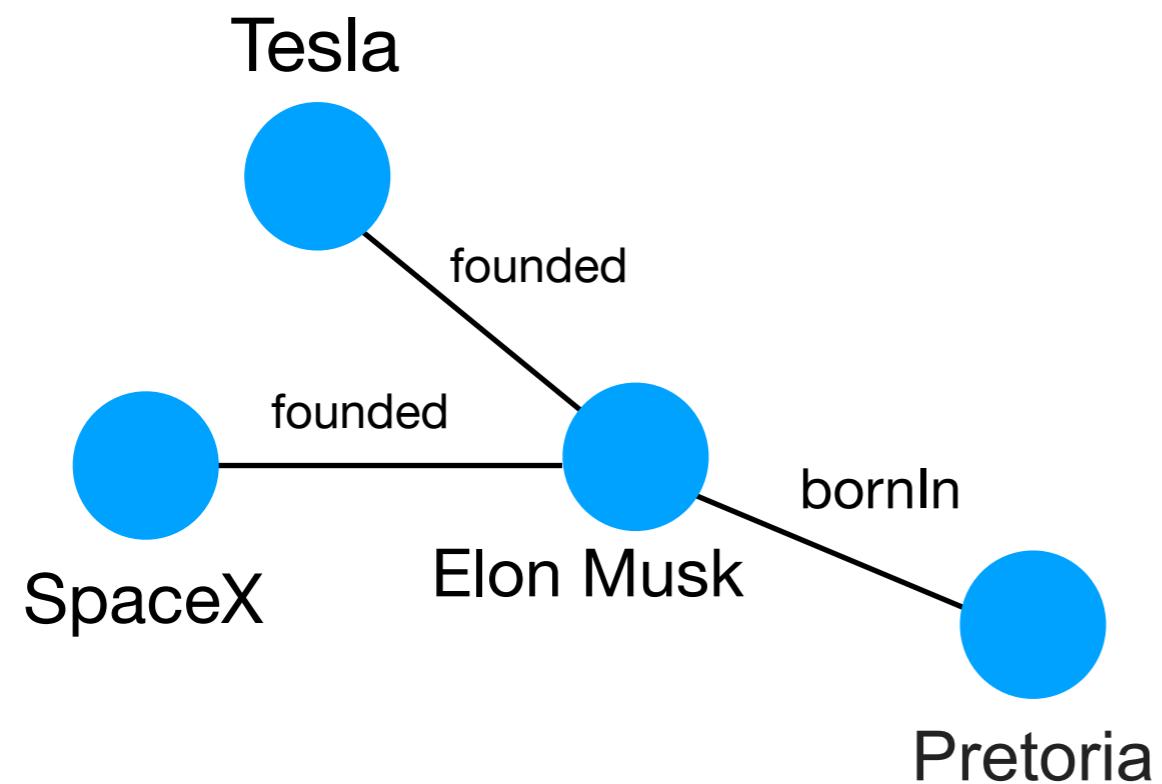
Svitlana Vakulenko, Javier Fernandez, Axel Polleres,
Maarten de Rijke, Michael Cochez

WU

WIRTSCHAFTS
UNIVERSITÄT
WIEN VIENNA
UNIVERSITY OF
ECONOMICS
AND BUSINESS

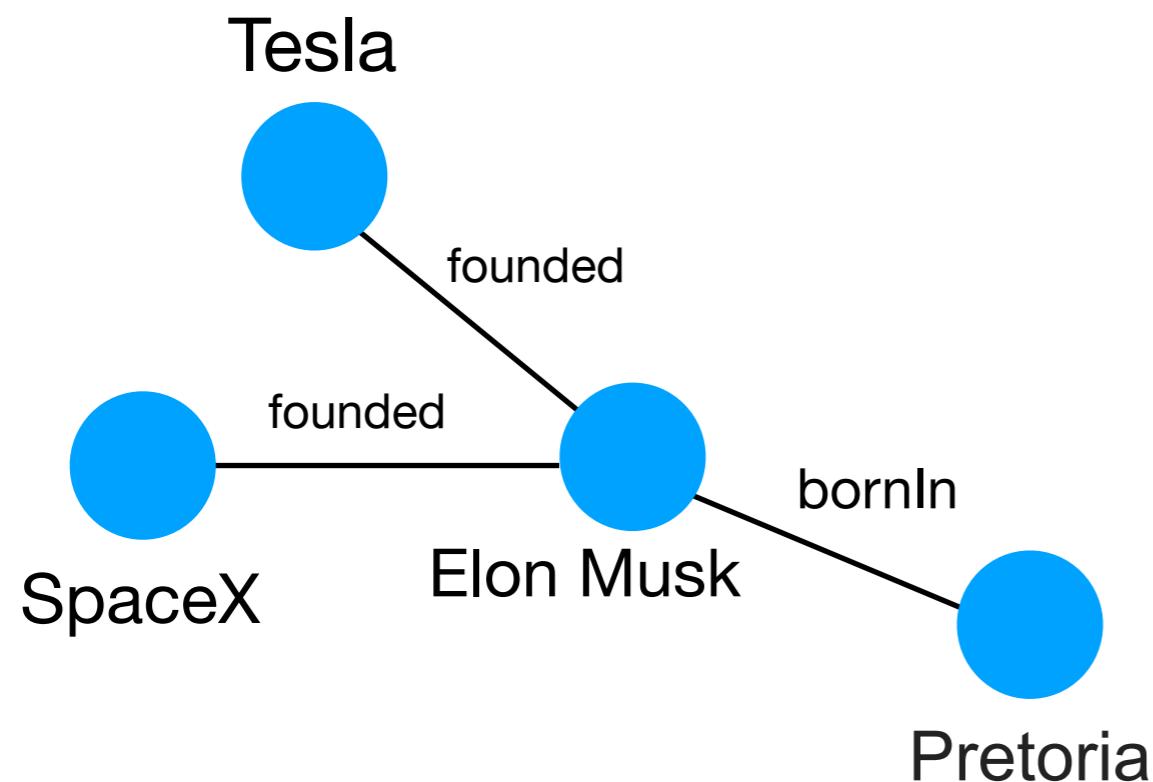


Knowledge Graphs

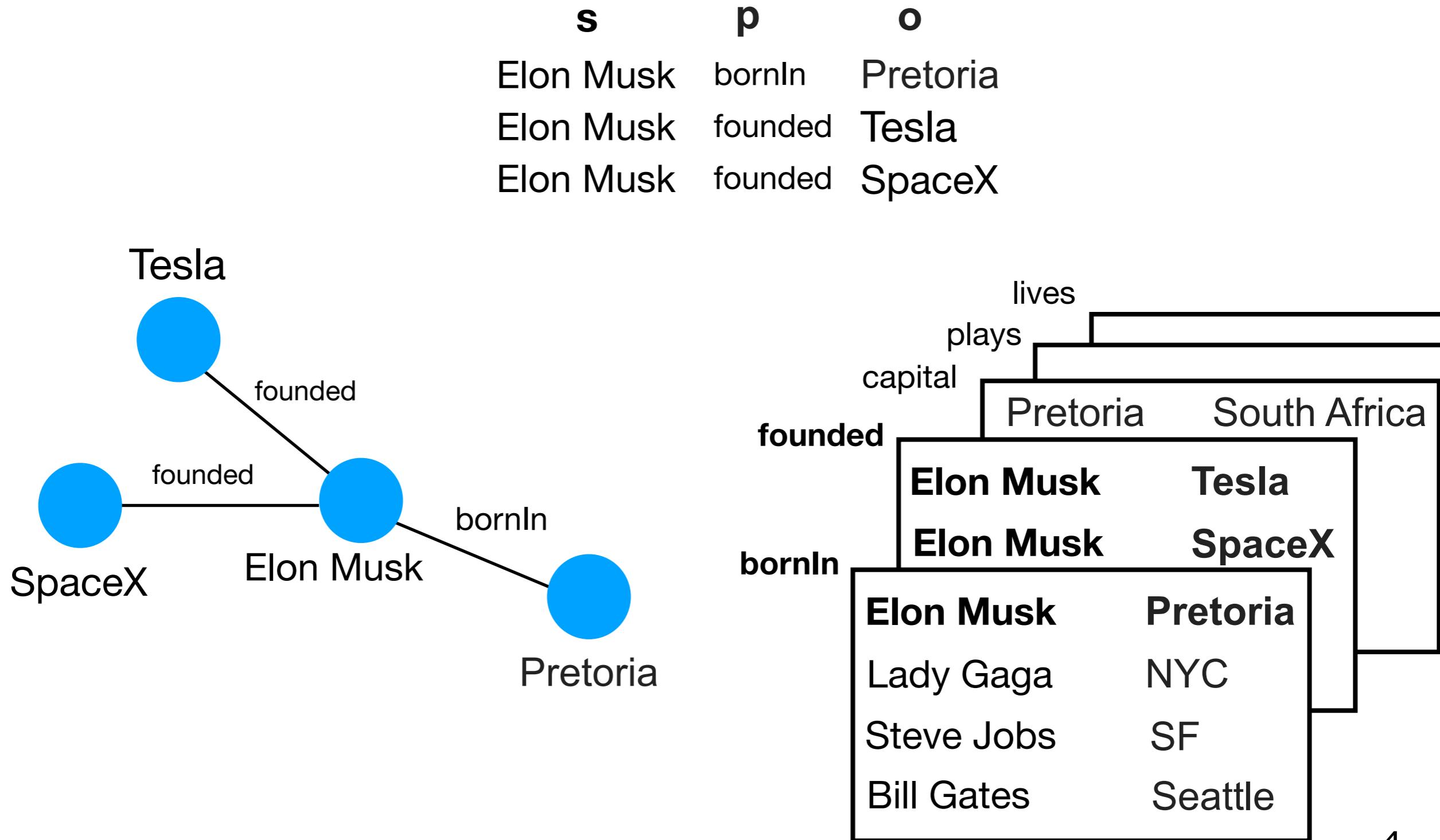


Knowledge Graphs

| s | p | o |
|-----------|---------|----------|
| Elon Musk | bornIn | Pretoria |
| Elon Musk | founded | Tesla |
| Elon Musk | founded | SpaceX |

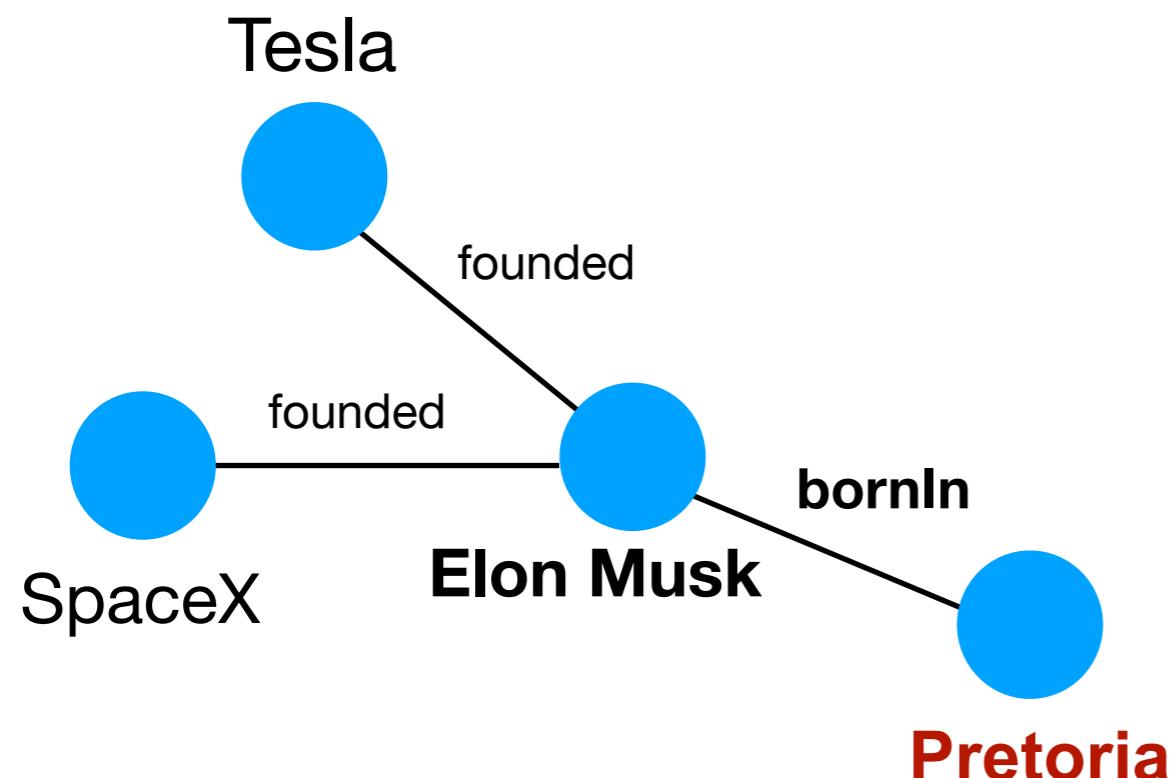


Knowledge Graphs

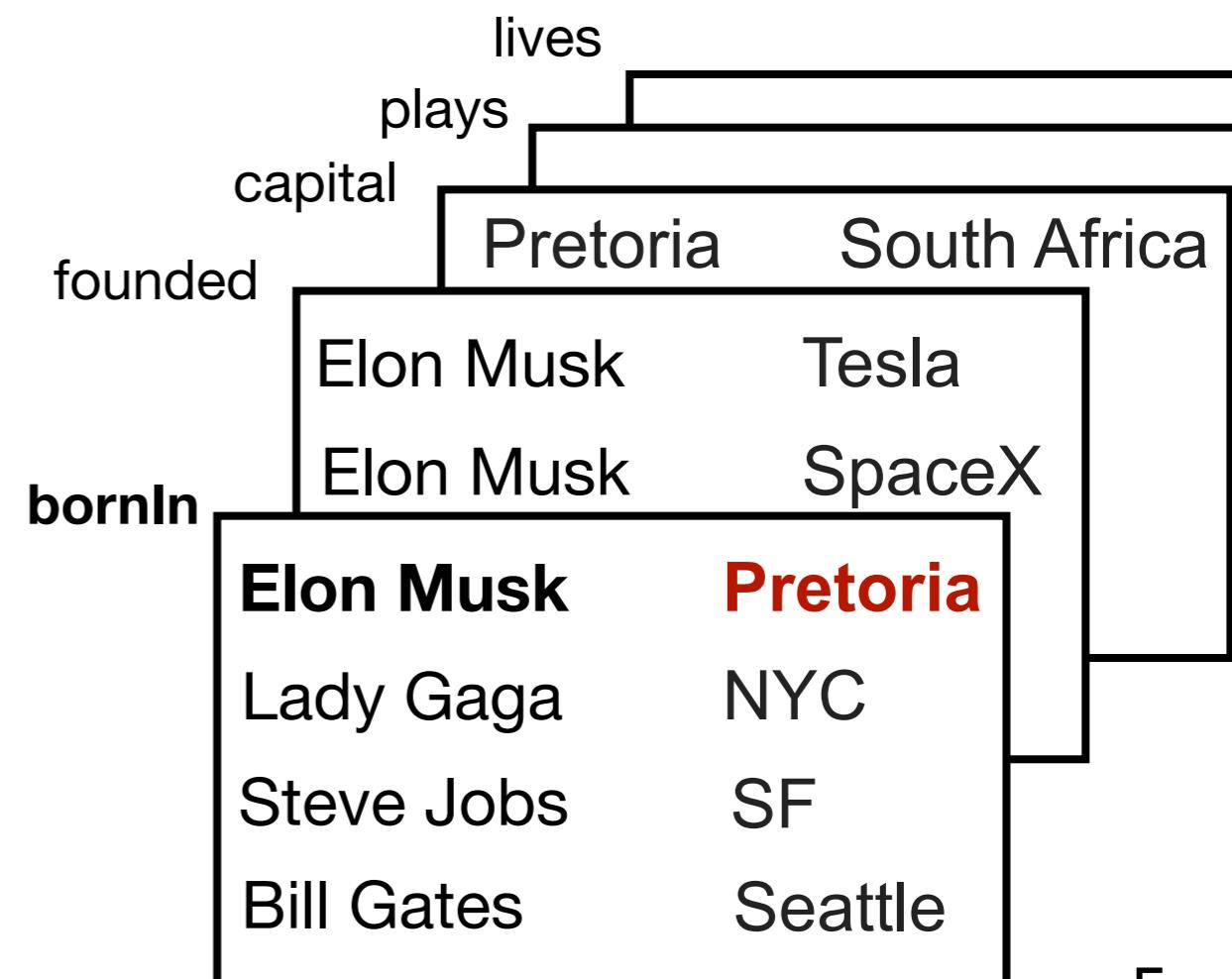


Simple Question Answering

Where is Elon Musk born?



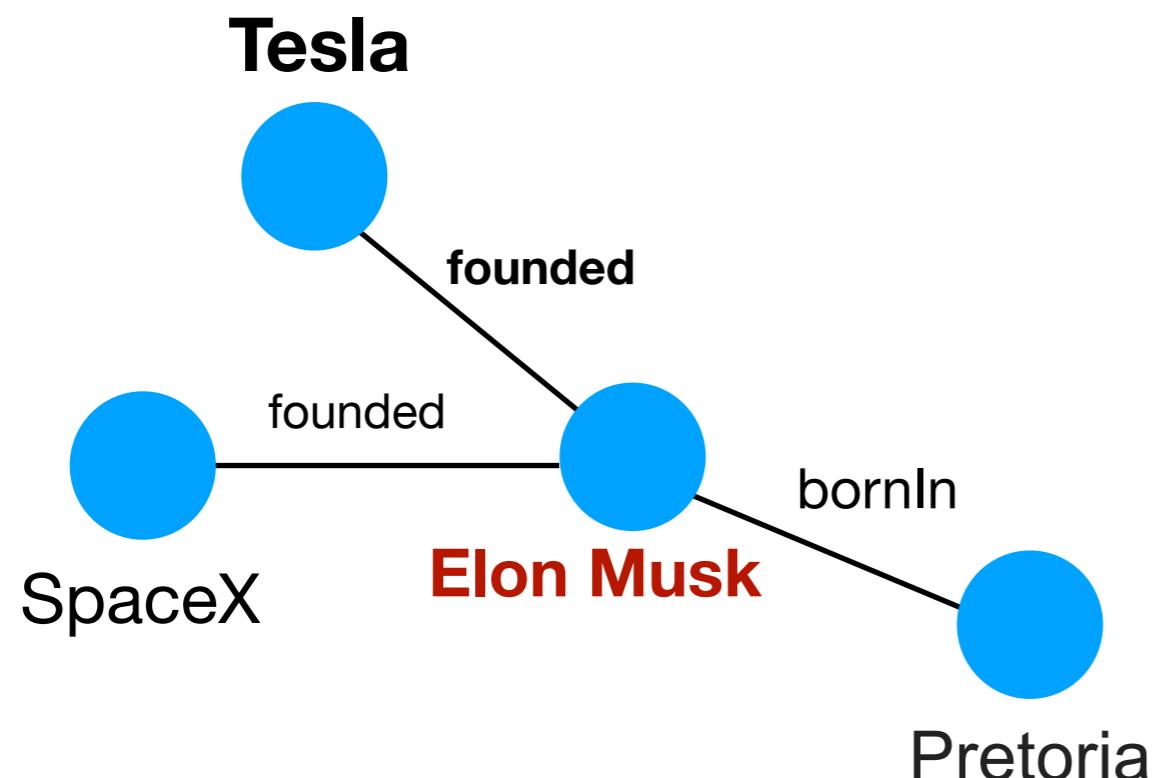
| s | p | o |
|-----------|---------|----------|
| Elon Musk | bornIn | Pretoria |
| Elon Musk | founded | Tesla |
| Elon Musk | founded | SpaceX |



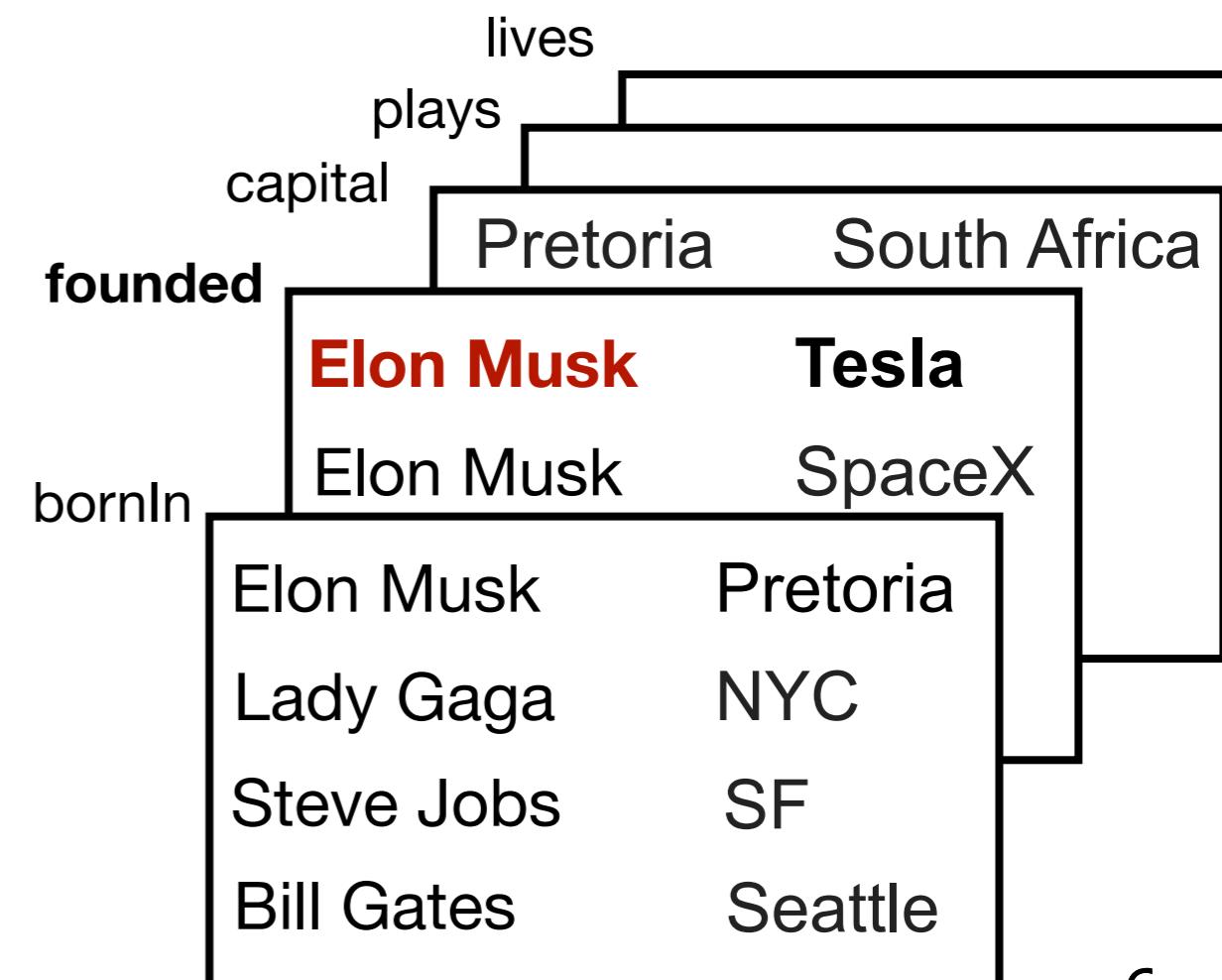
Simple Question Answering

Where is Elon Musk born?

Who is the founder of Tesla?



| s | p | o |
|------------------|---------|----------|
| Elon Musk | bornIn | Pretoria |
| Elon Musk | founded | Tesla |
| Elon Musk | founded | SpaceX |

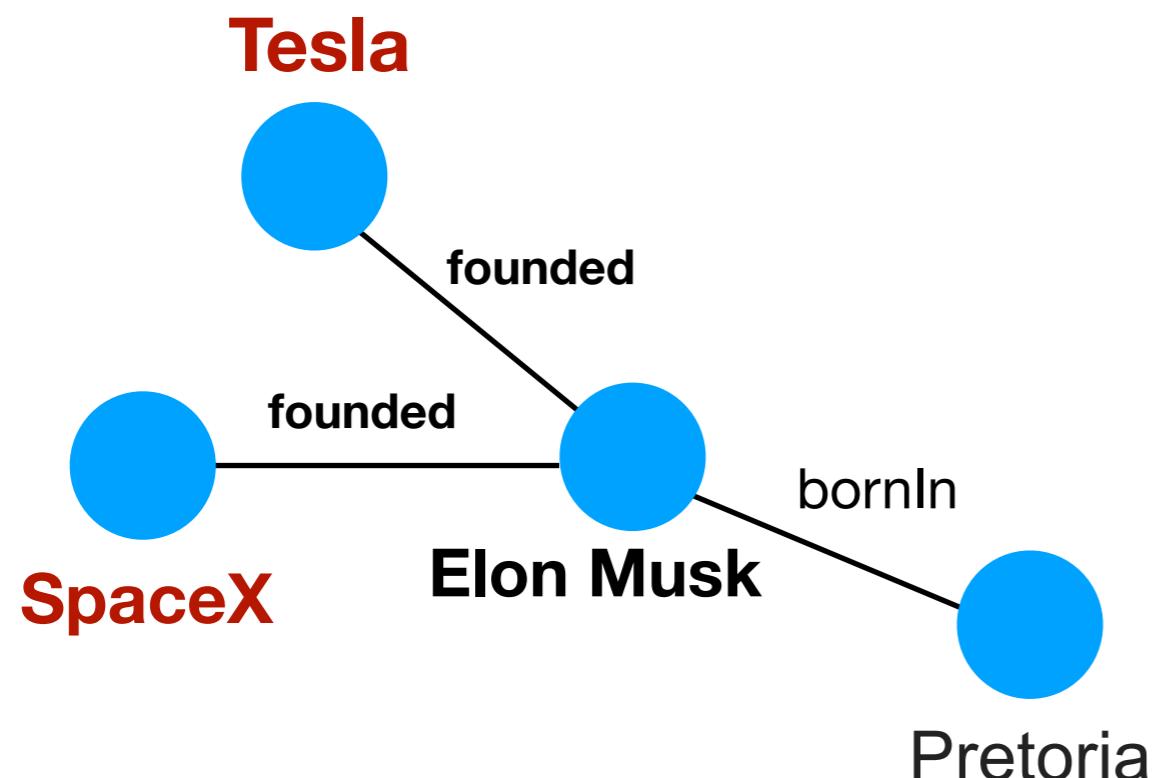


Simple Question Answering

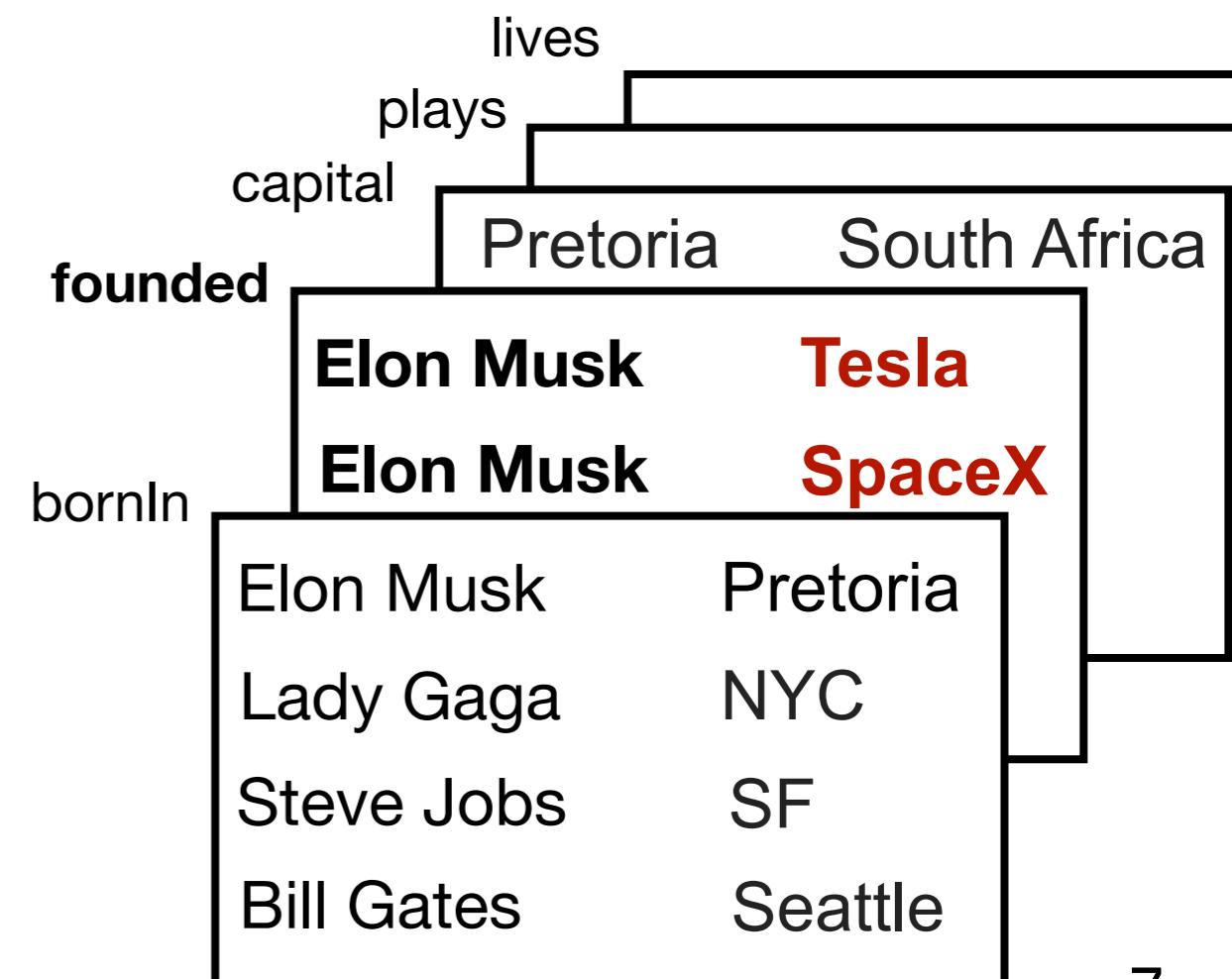
Where is Elon Musk born?

Who is the founder of Tesla?

What have Elon Musk founded?

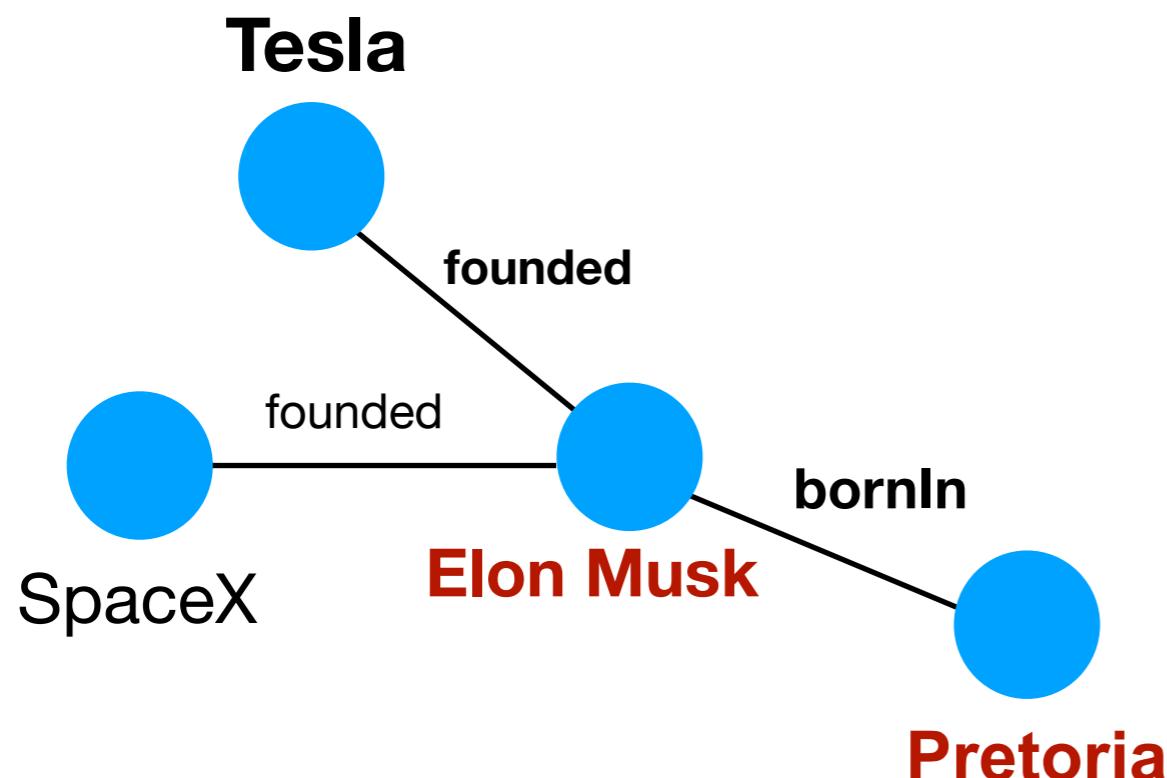


| s | p | o |
|-----------|---------|----------|
| Elon Musk | bornIn | Pretoria |
| Elon Musk | founded | Tesla |
| Elon Musk | founded | SpaceX |

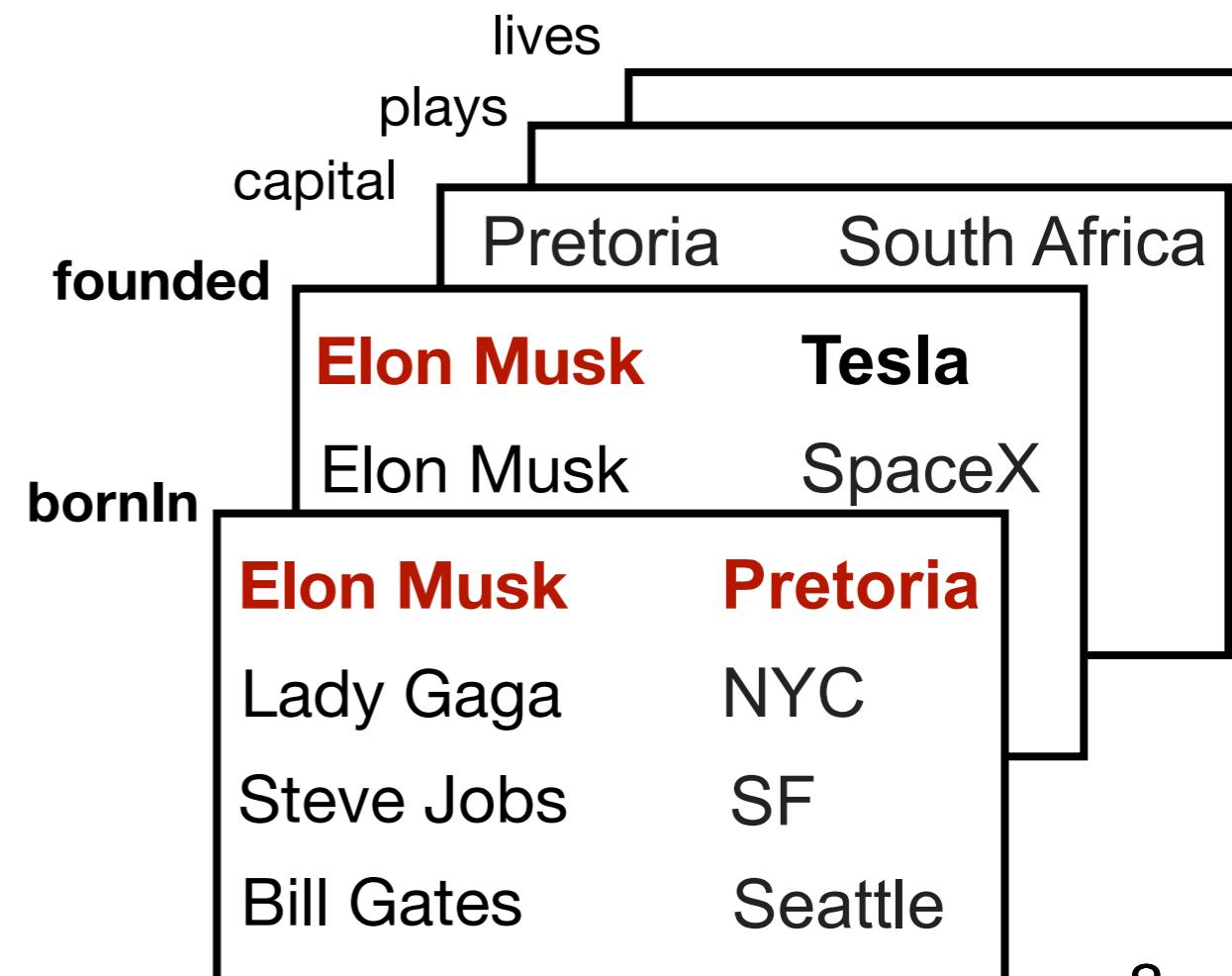


Complex Question Answering

Where is the founder of Tesla born?



| s | p | o |
|-----------|---------|----------|
| Elon Musk | bornIn | Pretoria |
| Elon Musk | founded | Tesla |
| Elon Musk | founded | SpaceX |



Approach

- Interpretation

- Parsing
- Matching

Where is the founder of Tesla born?

| | |
|--------------|-----|
| bornIn | 0.8 |
| founder | 1 |
| founded | 0.8 |
| Tesla | 1 |
| Nicola Tesla | 0.6 |
| Tesla coil | 0.5 |

Approach

- Interpretation

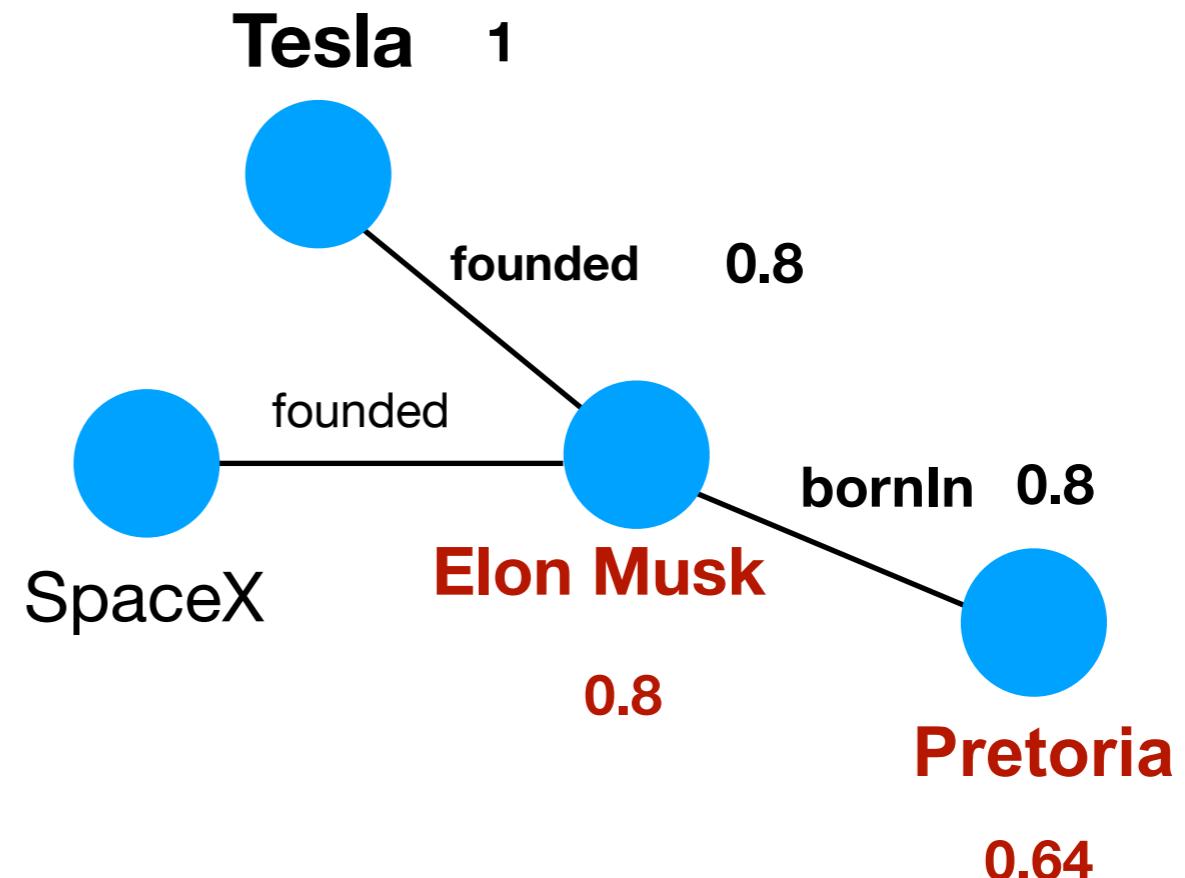
- Parsing
- Matching

- Reasoning

- Message Passing
- Score Aggregation

Where is the founder of Tesla born?

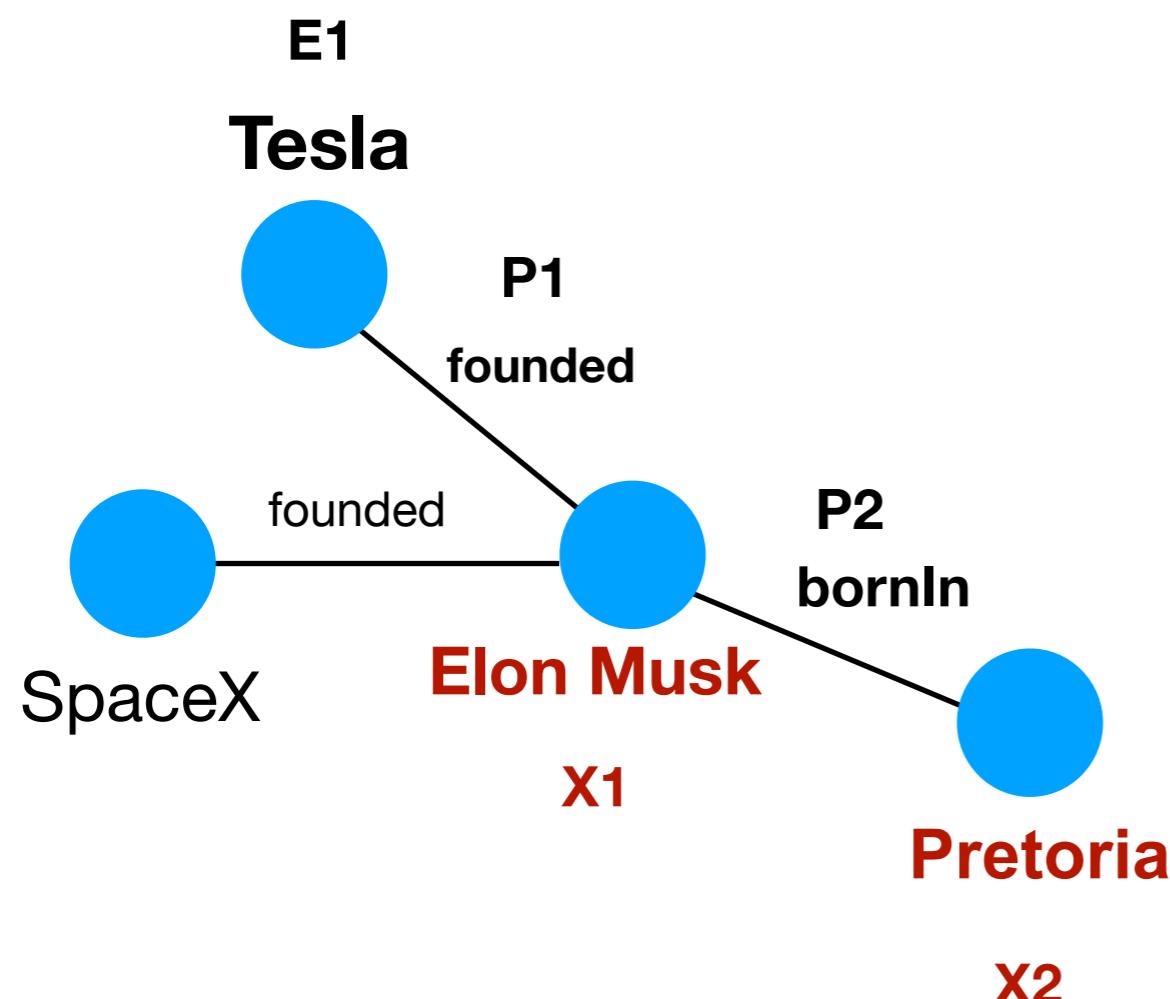
| | |
|--------------|-----|
| bornIn | 0.8 |
| founder | 1 |
| founded | 0.8 |
| Tesla | 1 |
| Nicola Tesla | 0.6 |
| Tesla coil | 0.5 |



Parsing: Sequence Labeling

Where is the founder of Tesla born?

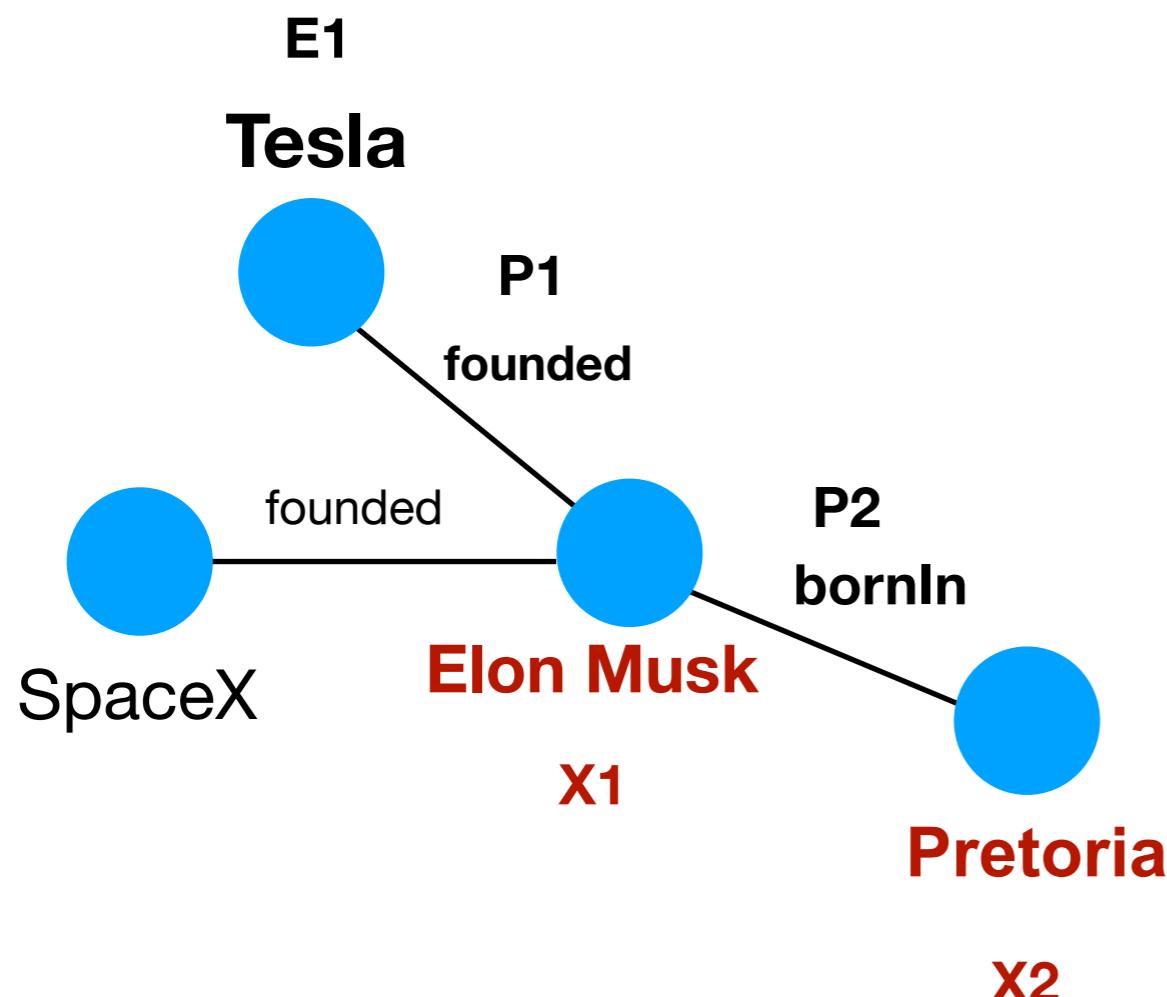
P1 E1 P2



Interpretation: Matching

Where is the founder of Tesla born?

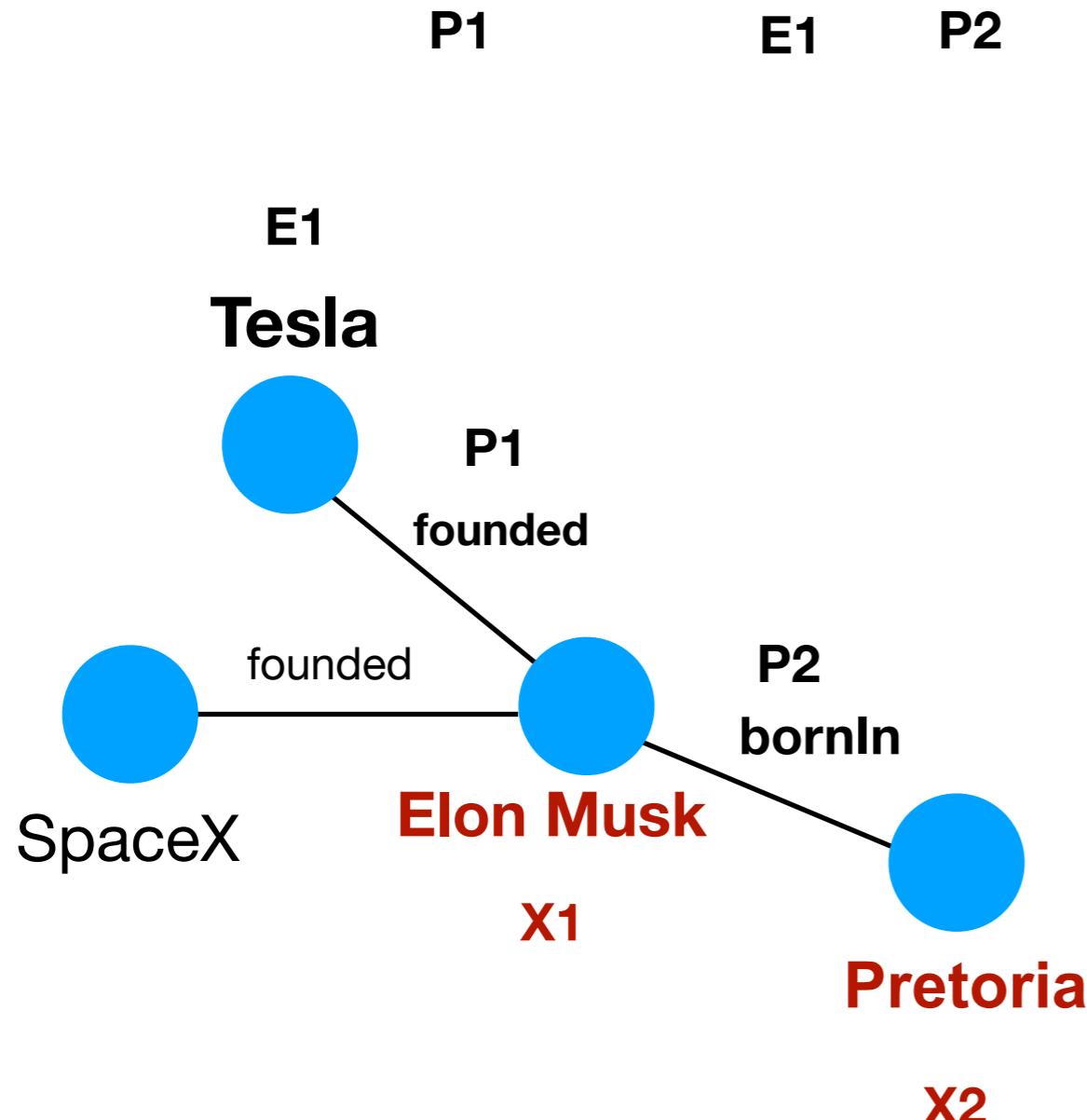
P1 E1 P2



| P1 | E1 |
|---------|-----|
| founder | 1 |
| founded | 0.8 |
| P2 | E1 |
| bornIn | 0.8 |

Reasoning: Message Passing

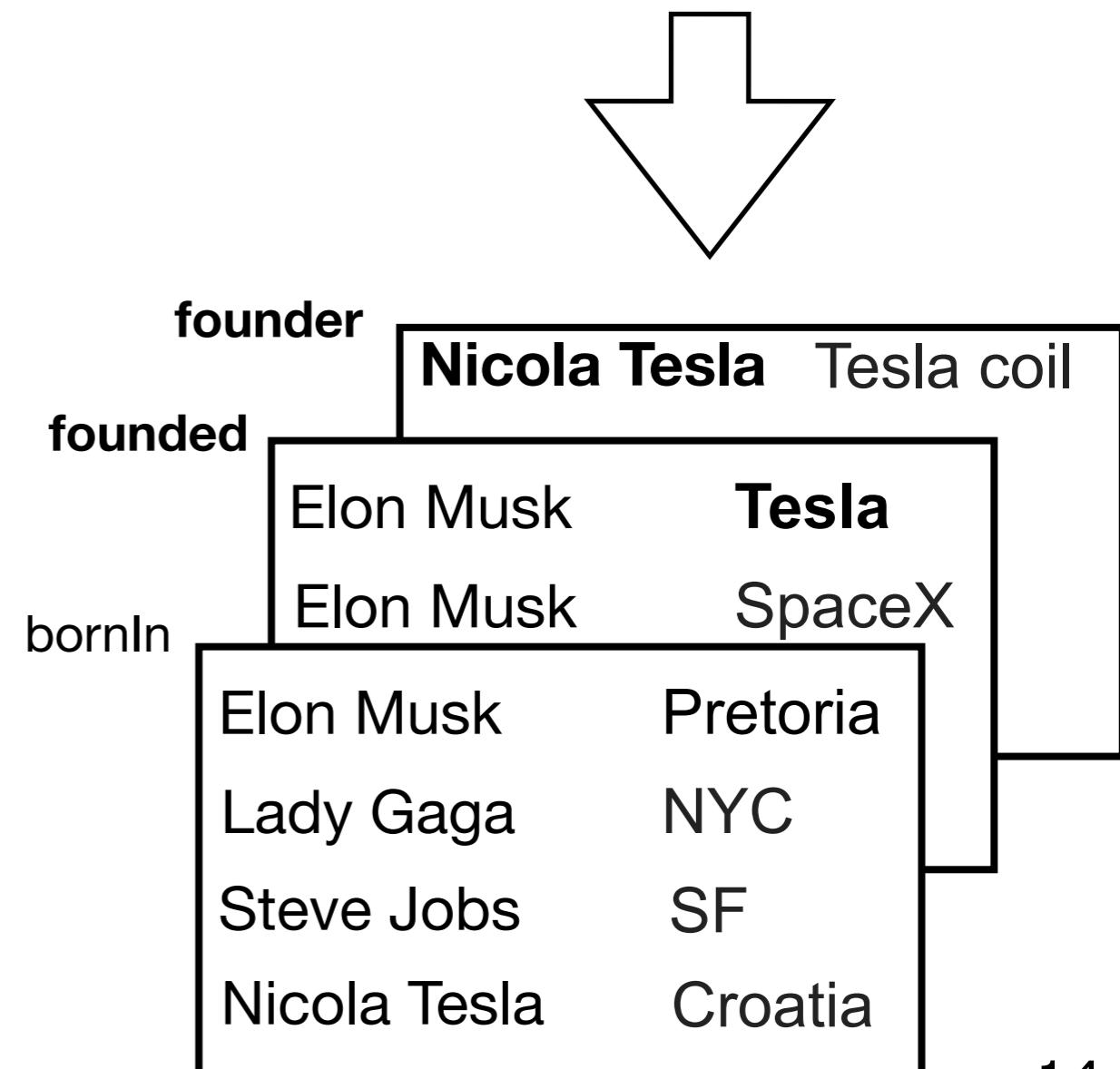
Where is the founder of Tesla born?



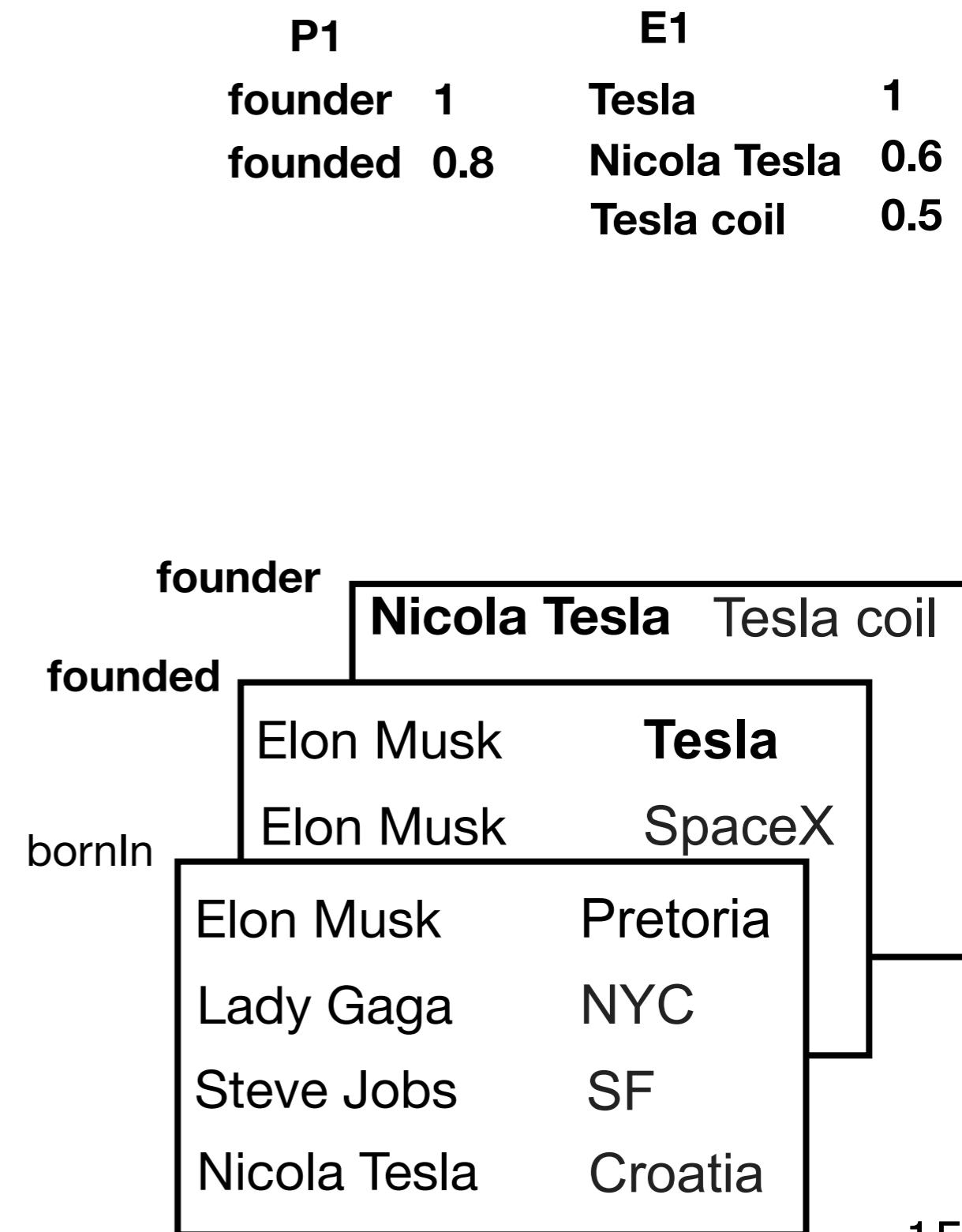
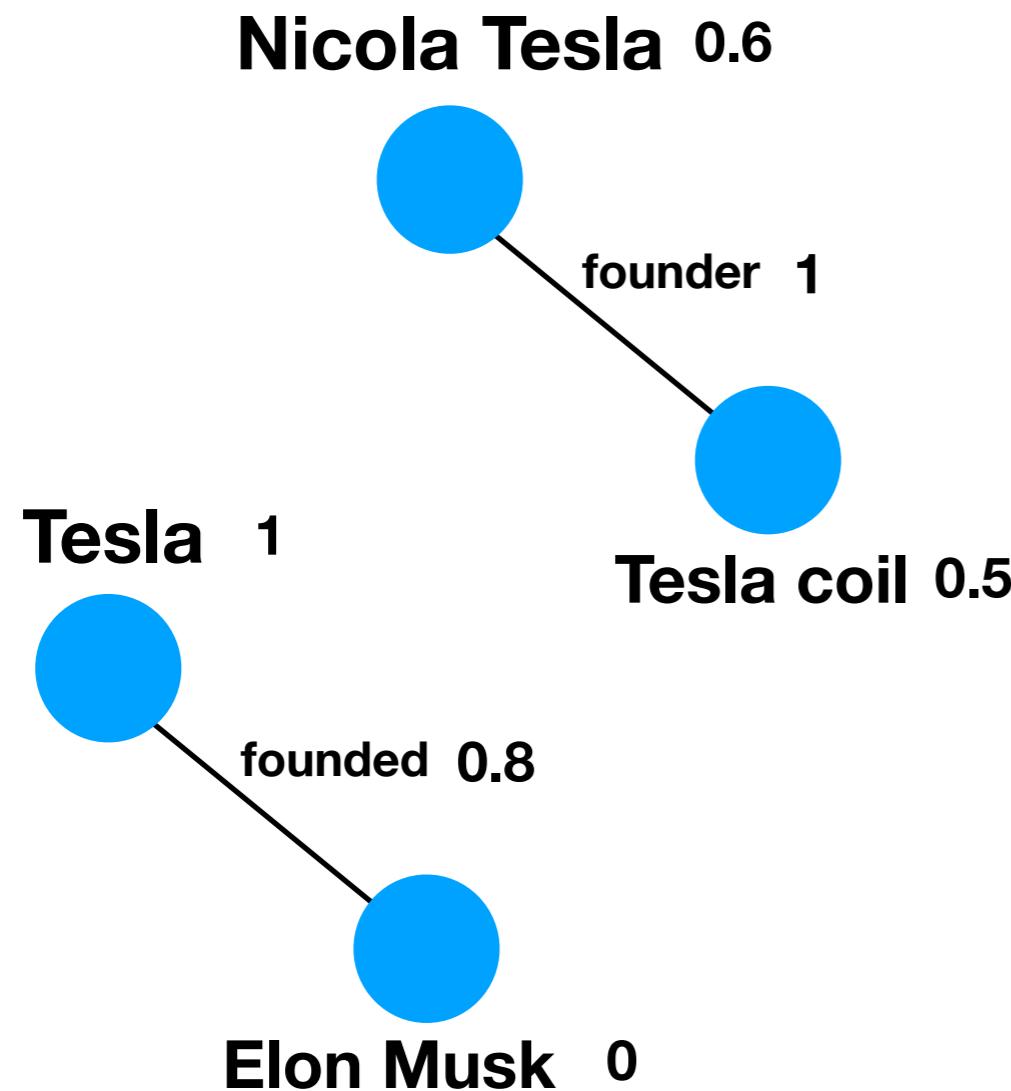
| P1 | E1 |
|---------------------|-------------------|
| founder | 1 |
| founded | 0.8 |
| | Tesla 1 |
| | Nicola Tesla 0.6 |
| | Tesla coil 0.5 |
| | |
| P2 | |
| bornIn | 0.8 |
| | |
| founder | |
| founded | |
| bornIn | |
| Nicola Tesla | Tesla coil |
| Elon Musk | Tesla |
| Elon Musk | SpaceX |
| Elon Musk | Pretoria |
| Lady Gaga | NYC |
| Steve Jobs | SF |
| Nicola Tesla | Croatia |

Message Passing: 1st Hop

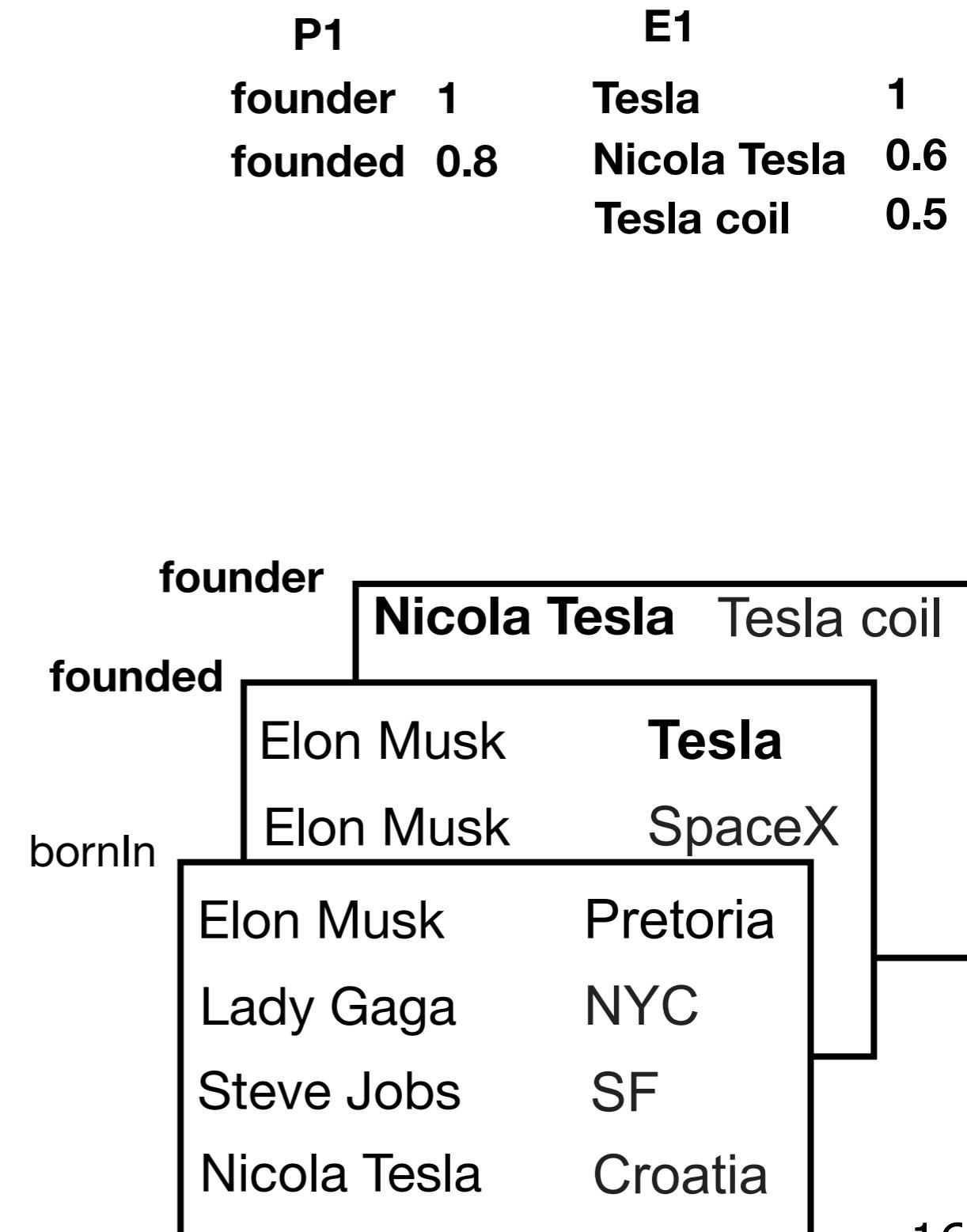
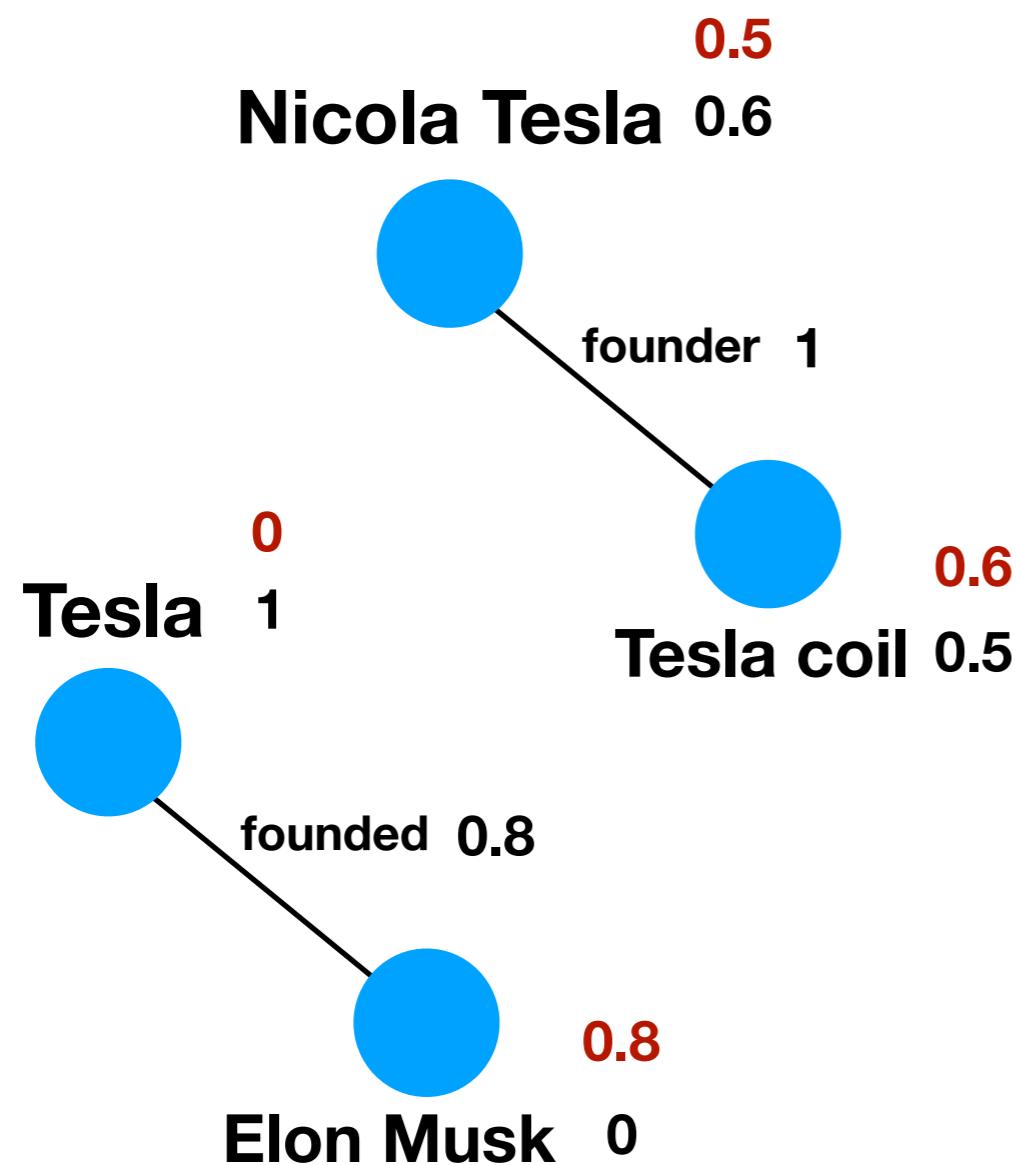
| P1 | E1 |
|-------------|------------------|
| founder 1 | Tesla 1 |
| founded 0.8 | Nicola Tesla 0.6 |
| | Tesla coil 0.5 |



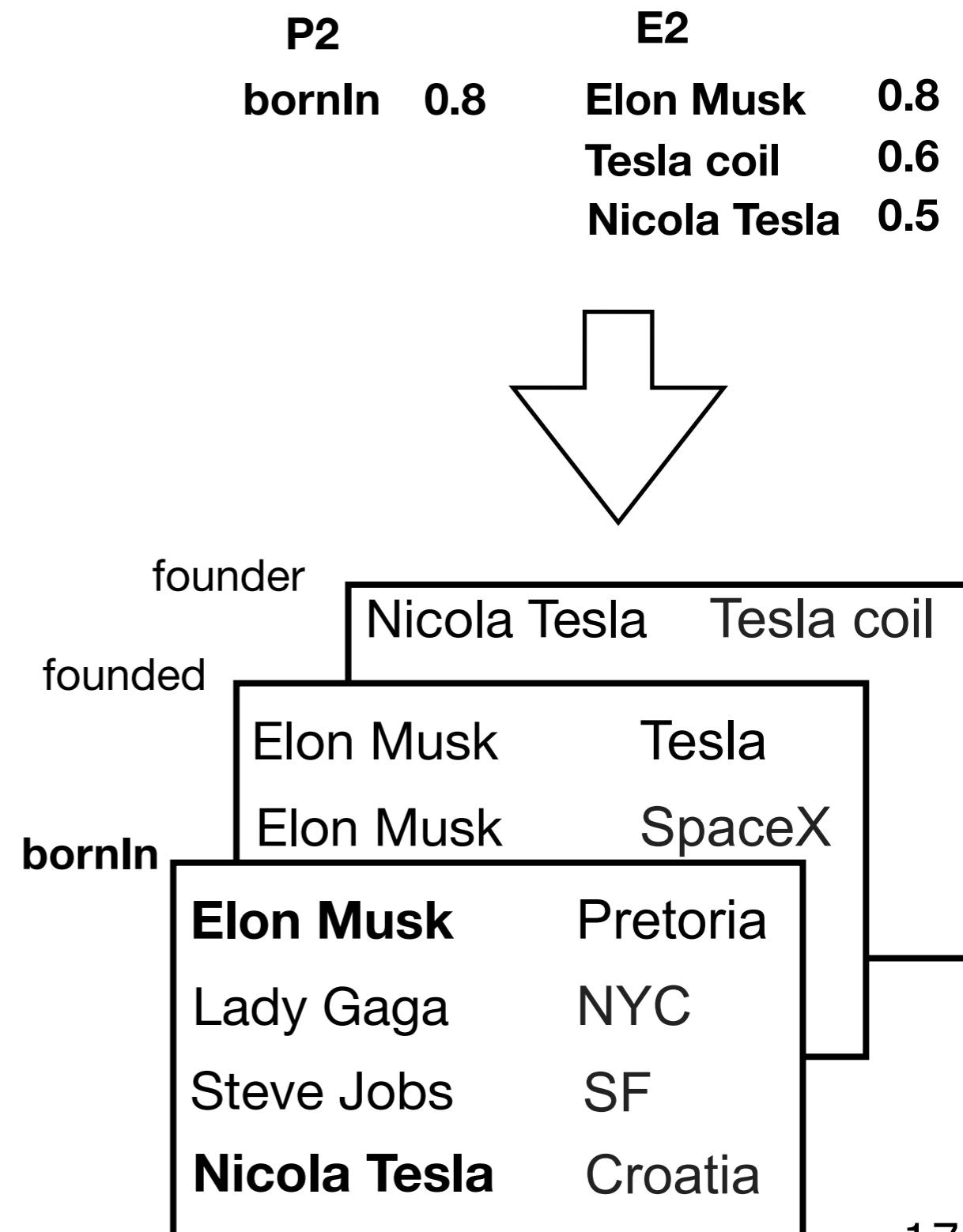
Message Passing: 1st Hop



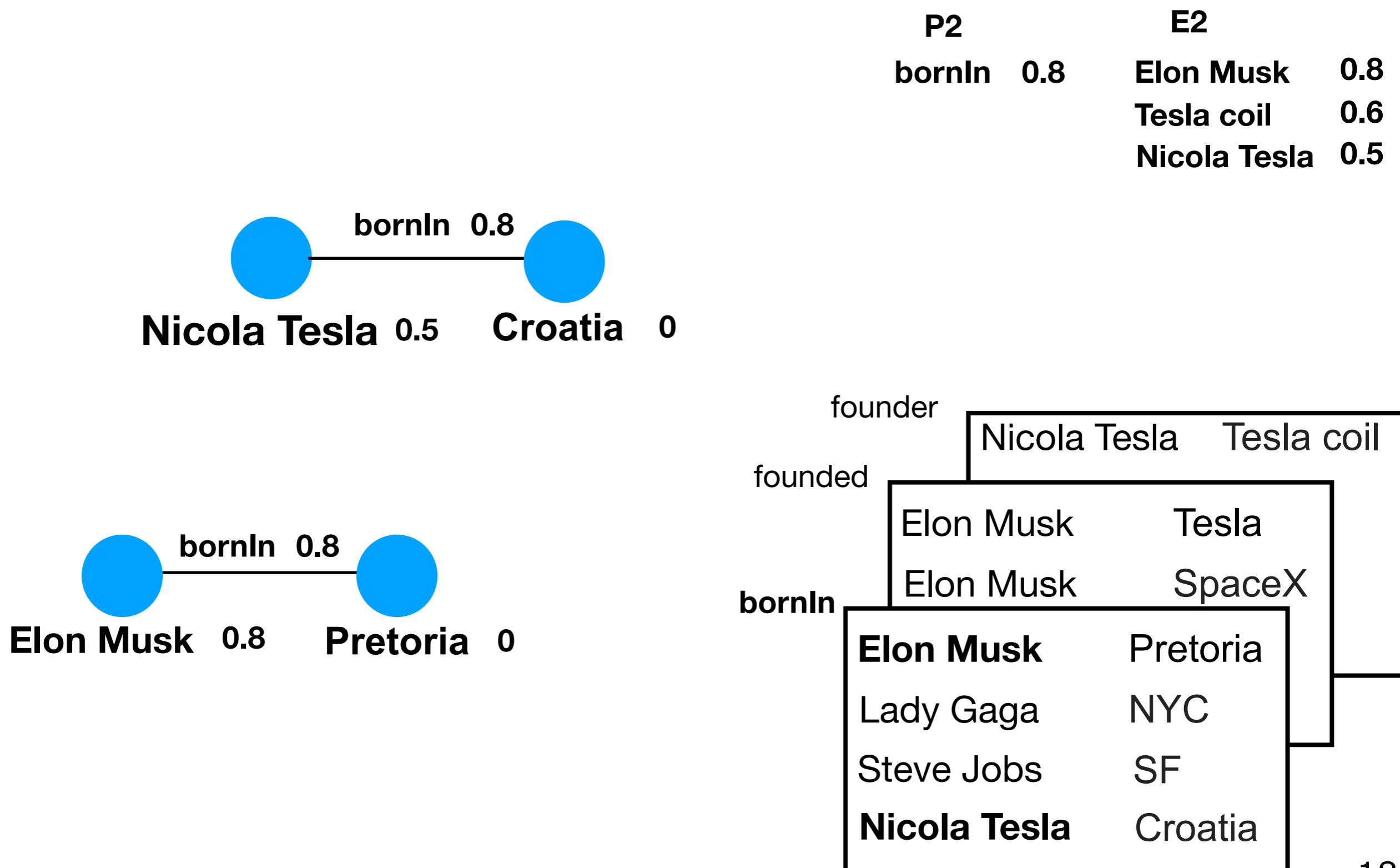
Message Passing: 1st Hop



Message Passing: 2nd Hop

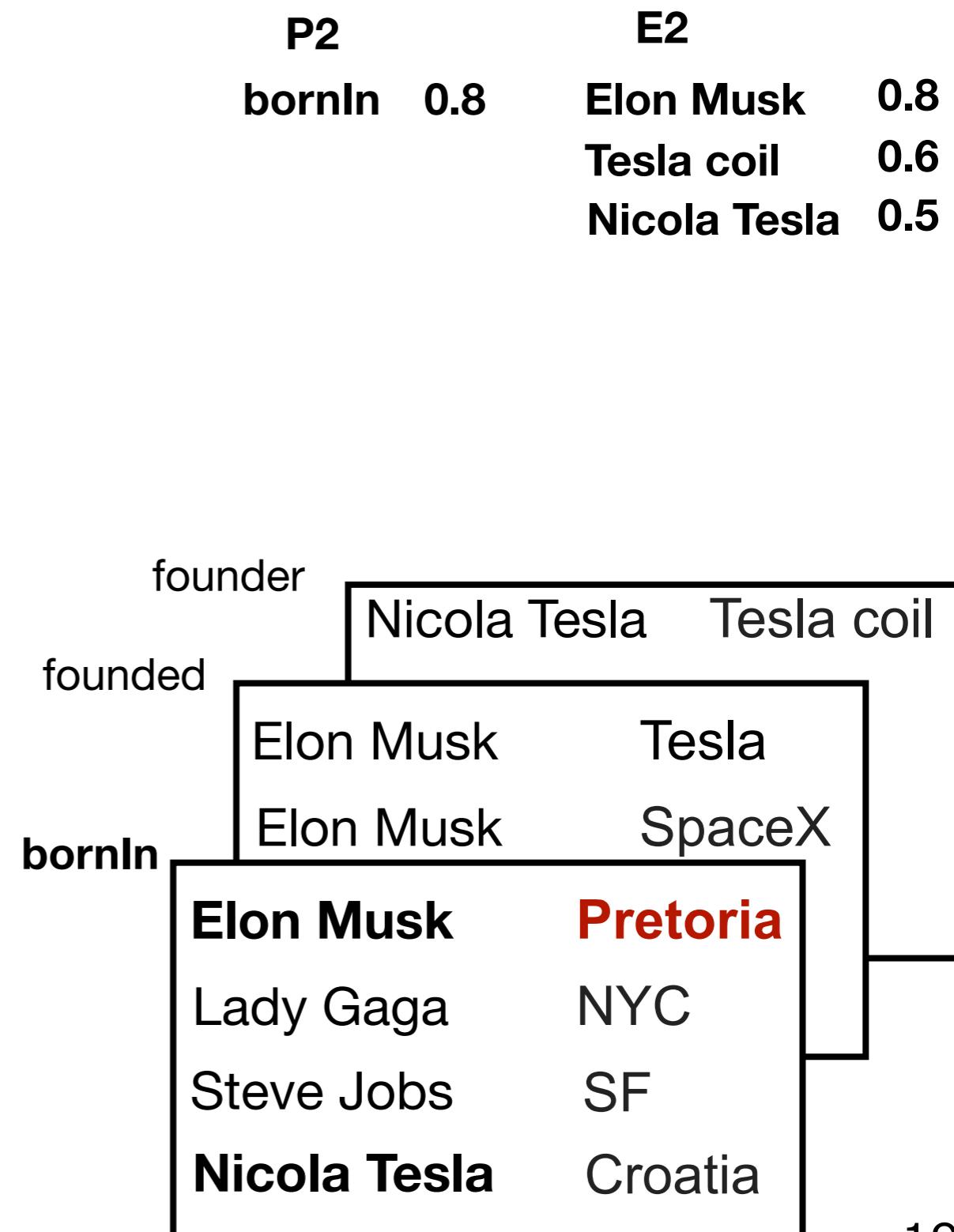
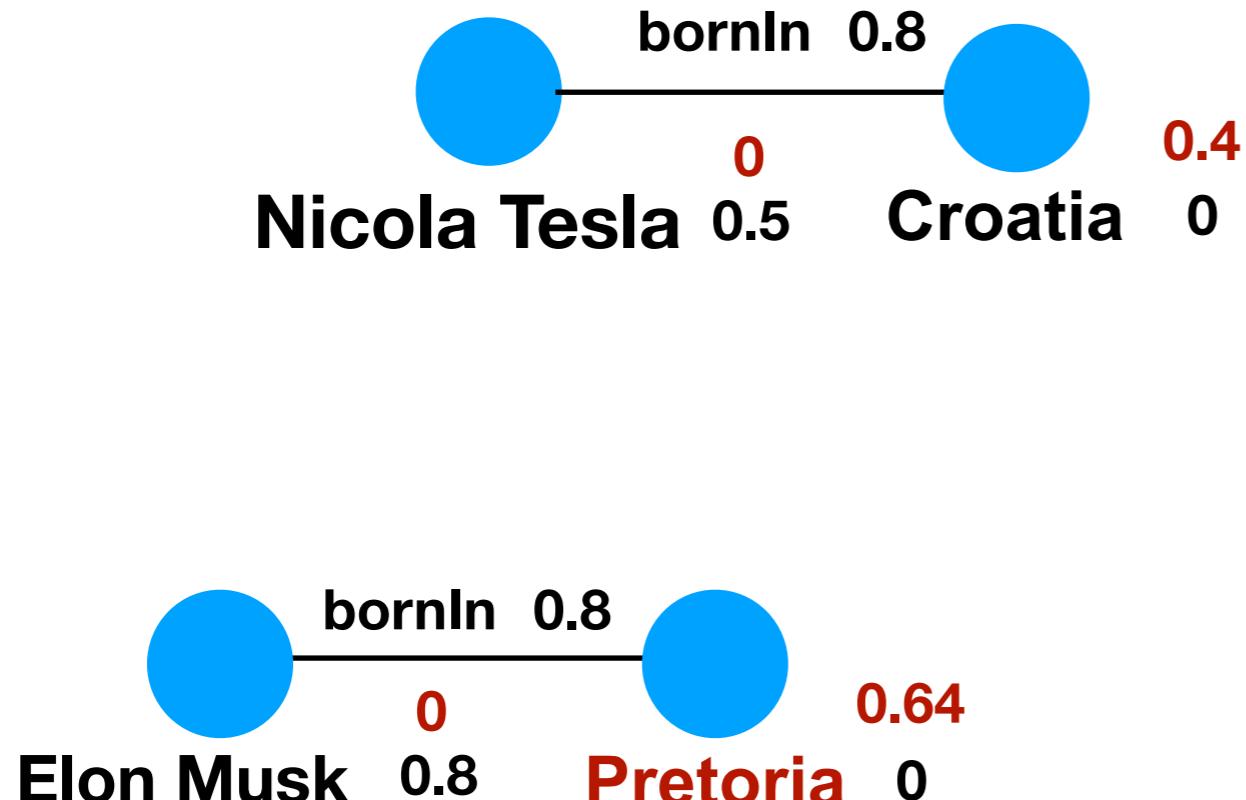


Message Passing: 2nd Hop



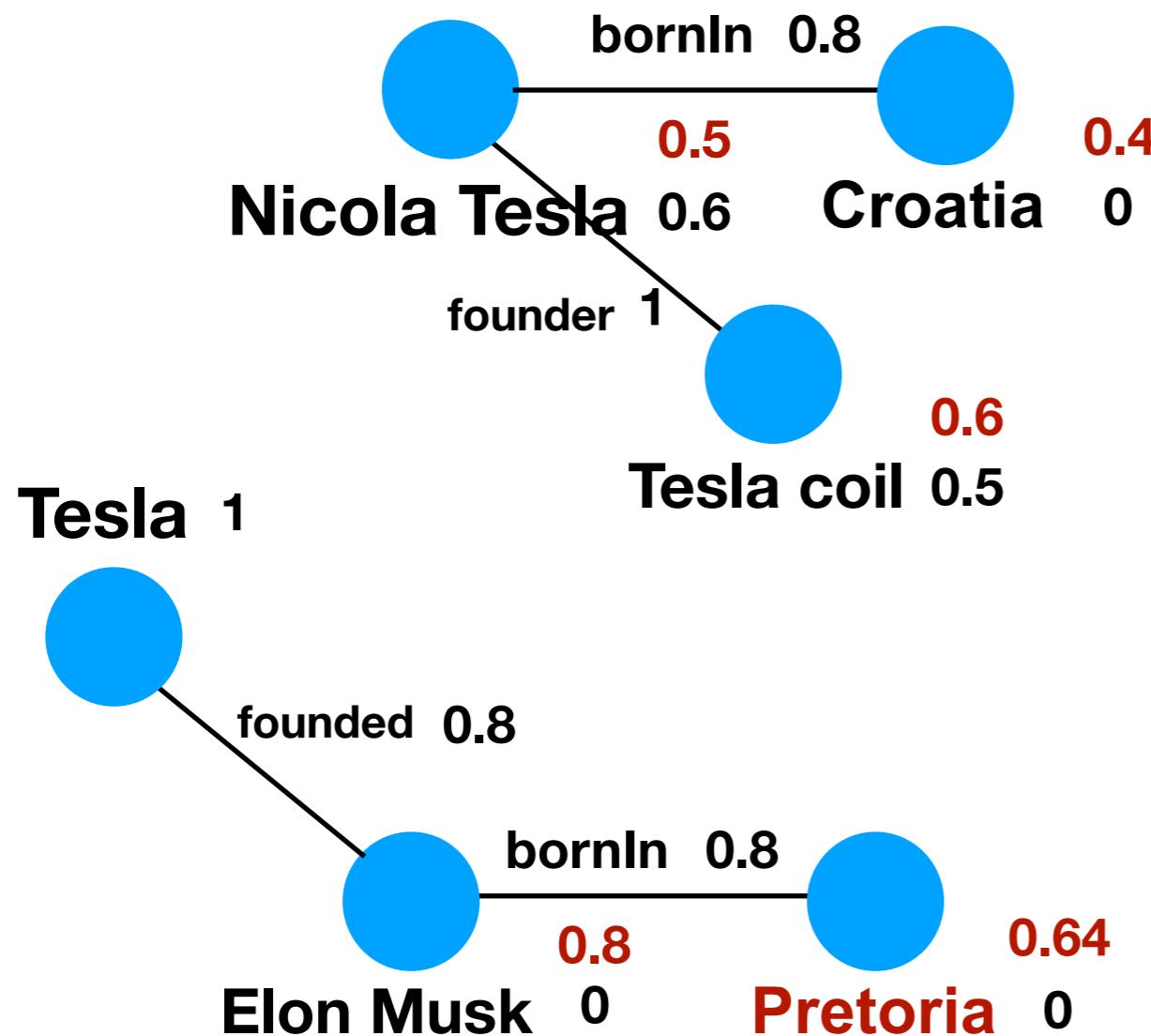
Message Passing: 2nd Hop

Where is the founder of Tesla born?



Message Passing: Explanation

Where is the founder of Tesla born?



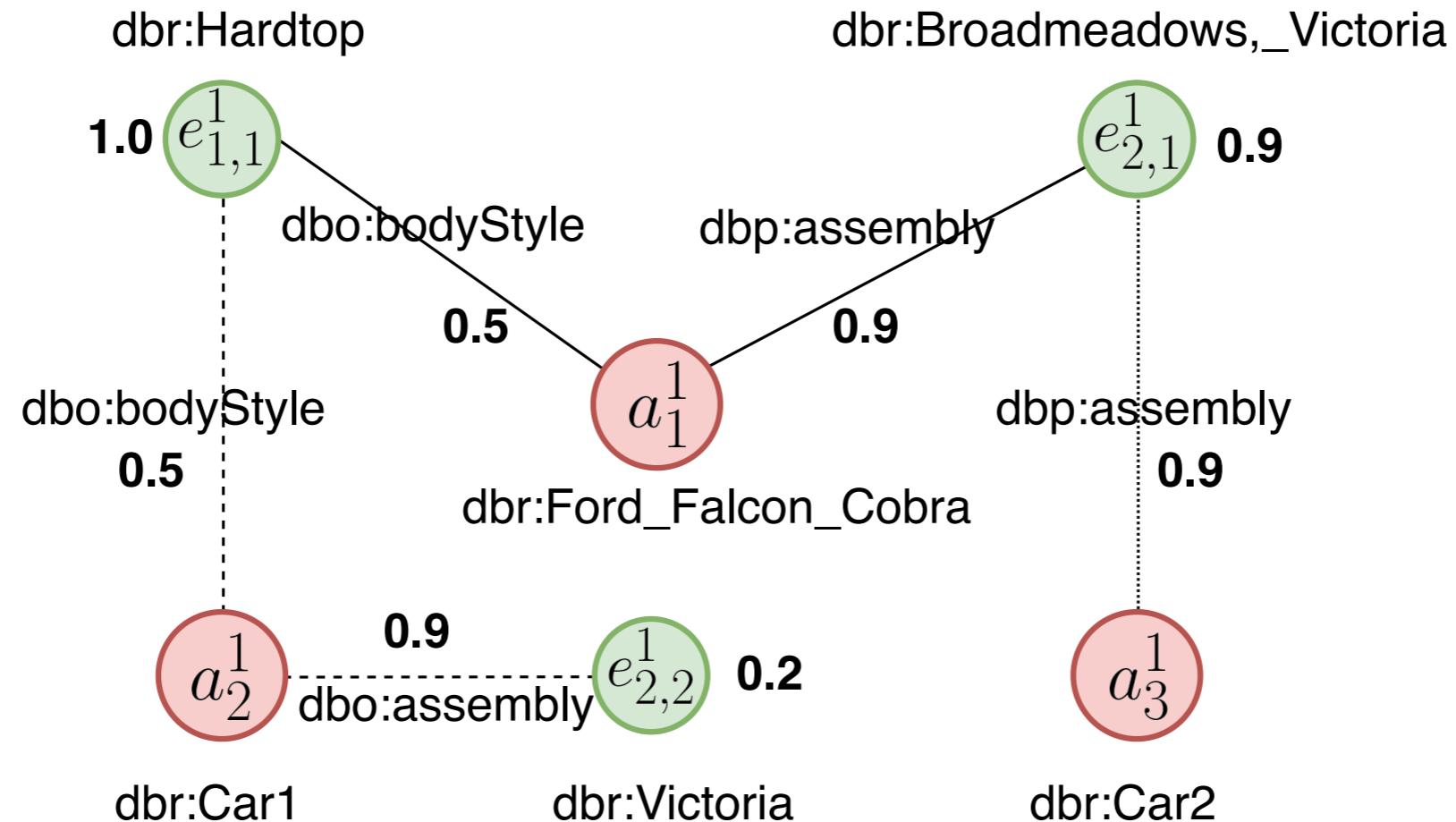
| | P1 | E1 |
|---------|--------------|--------------|
| founder | 1 | Tesla |
| founded | 0.8 | Nicola Tesla |
| | | Tesla coil |
| | | 0.5 |
| | P2 | E2 |
| bornIn | 0.8 | Elon Musk |
| | | Tesla coil |
| | | Nicola Tesla |
| | | 0.5 |
| founder | Nicola Tesla | |
| founded | Tesla coil | |
| bornIn | Elon Musk | |
| | Elon Musk | Tesla |
| | Elon Musk | SpaceX |
| | Elon Musk | Pretoria |
| | Lady Gaga | NYC |
| | Steve Jobs | SF |
| | Nicola Tesla | Croatia |

Reasoning: Score Aggregation

Which **hardtop** car is assembled in **Broadmeadows, Victoria?**

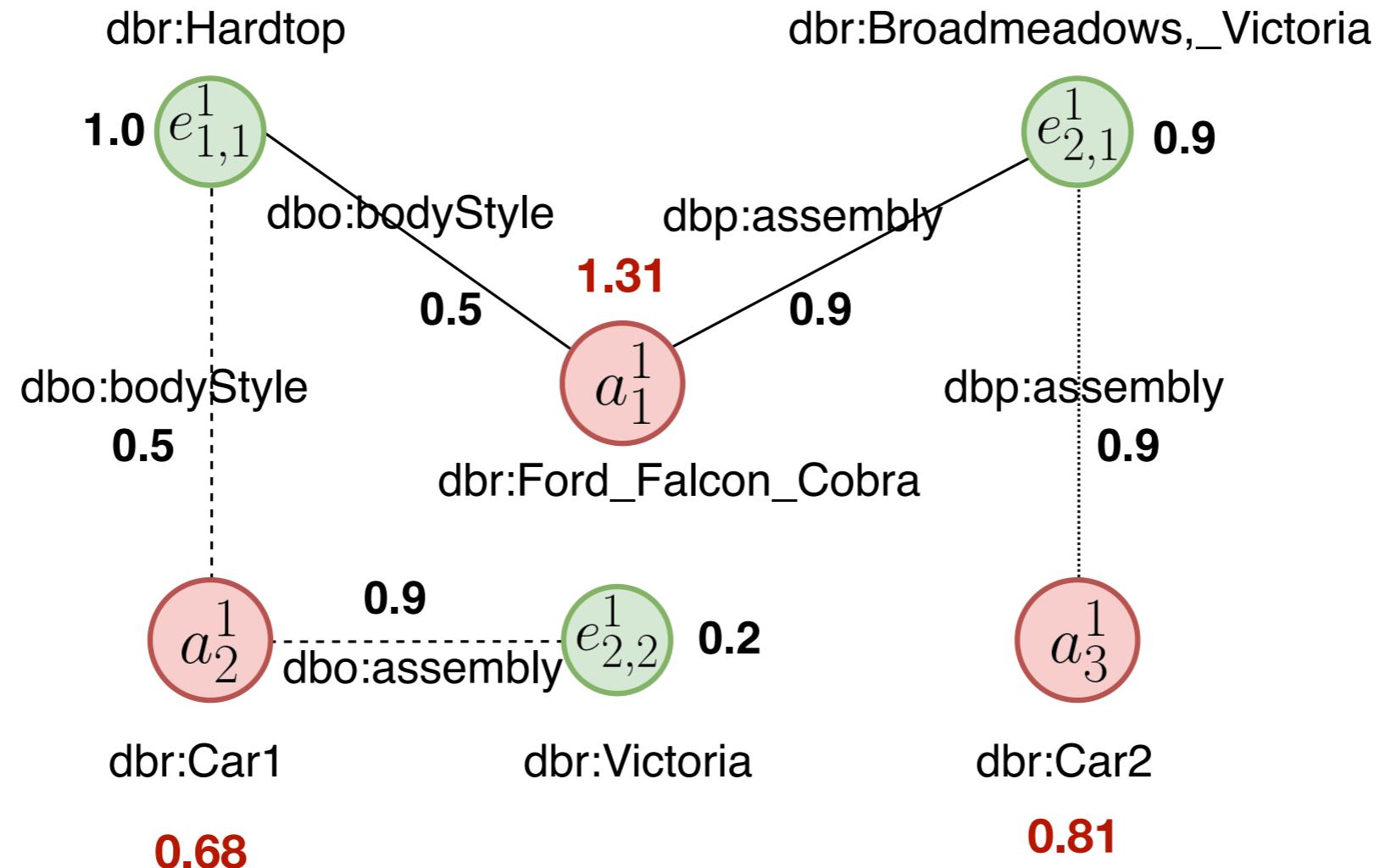
Reasoning: Score Aggregation

Which **hardtop** car is assembled in **Broadmeadows, Victoria**?



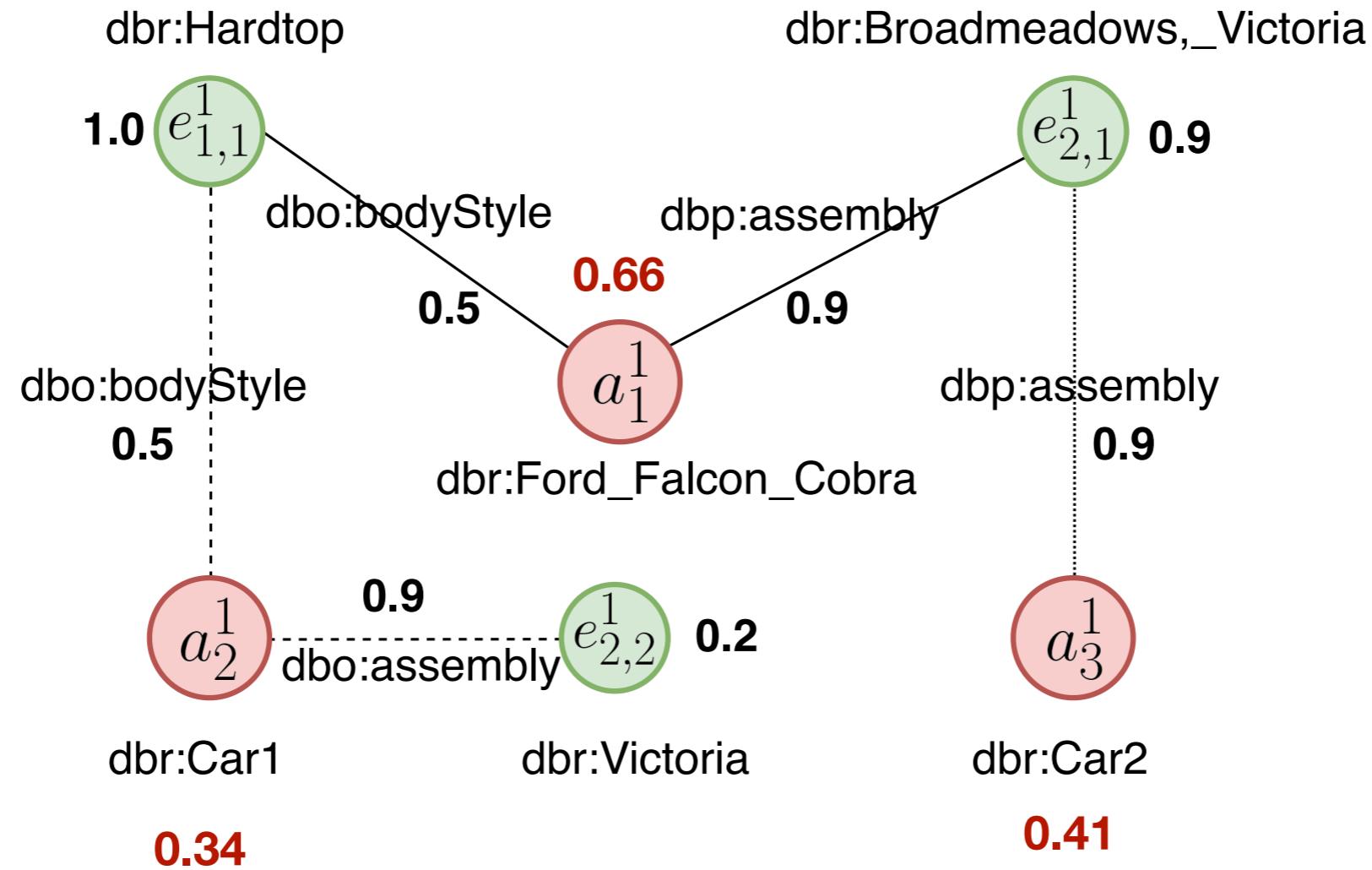
Reasoning: Score Aggregation

Which **hardtop** car is assembled in **Broadmeadows, Victoria**?



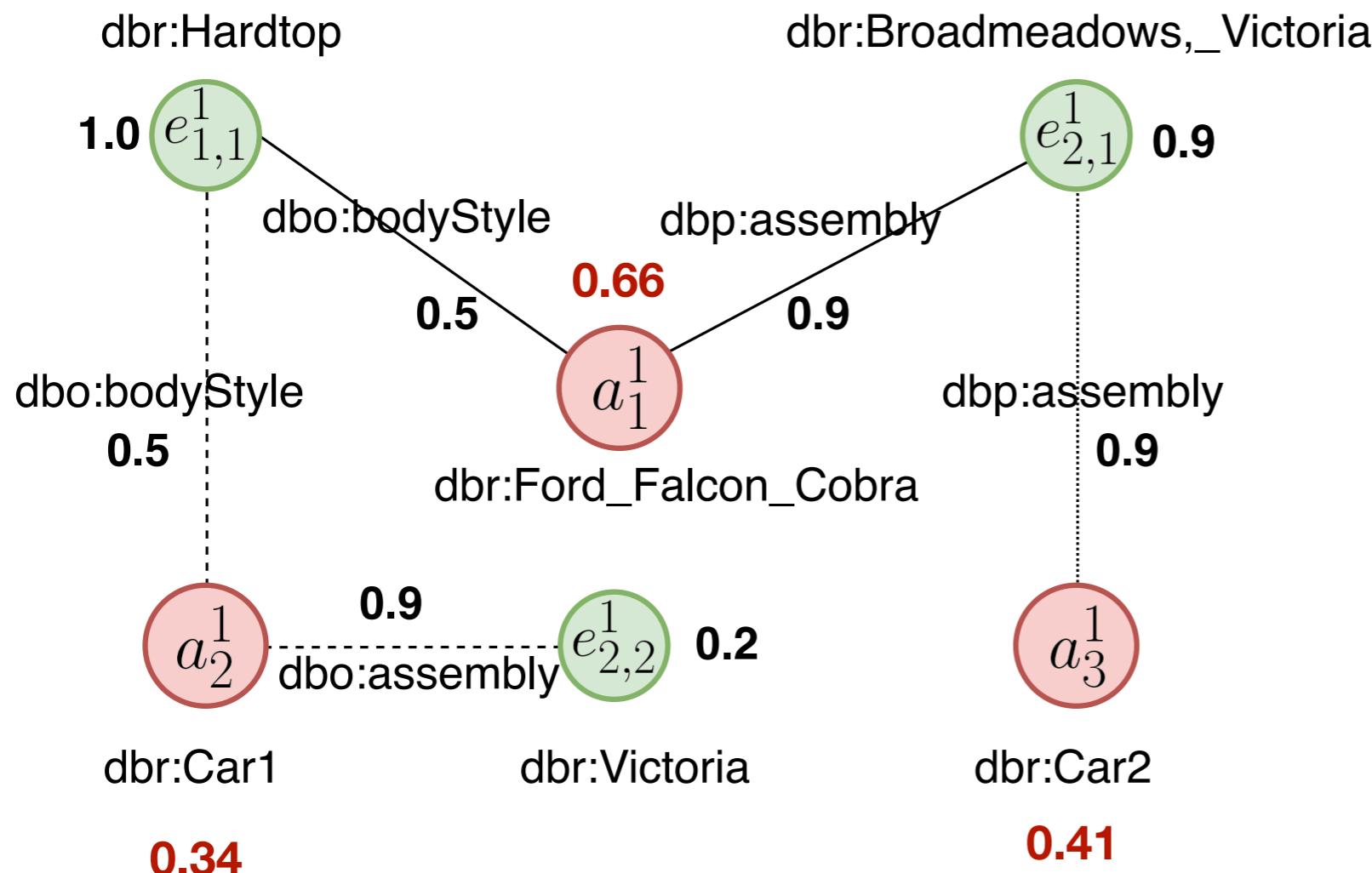
Aggregation: Score Normalization

Which **hardtop** car is assembled in **Broadmeadows, Victoria**?



Aggregation: Score Normalization

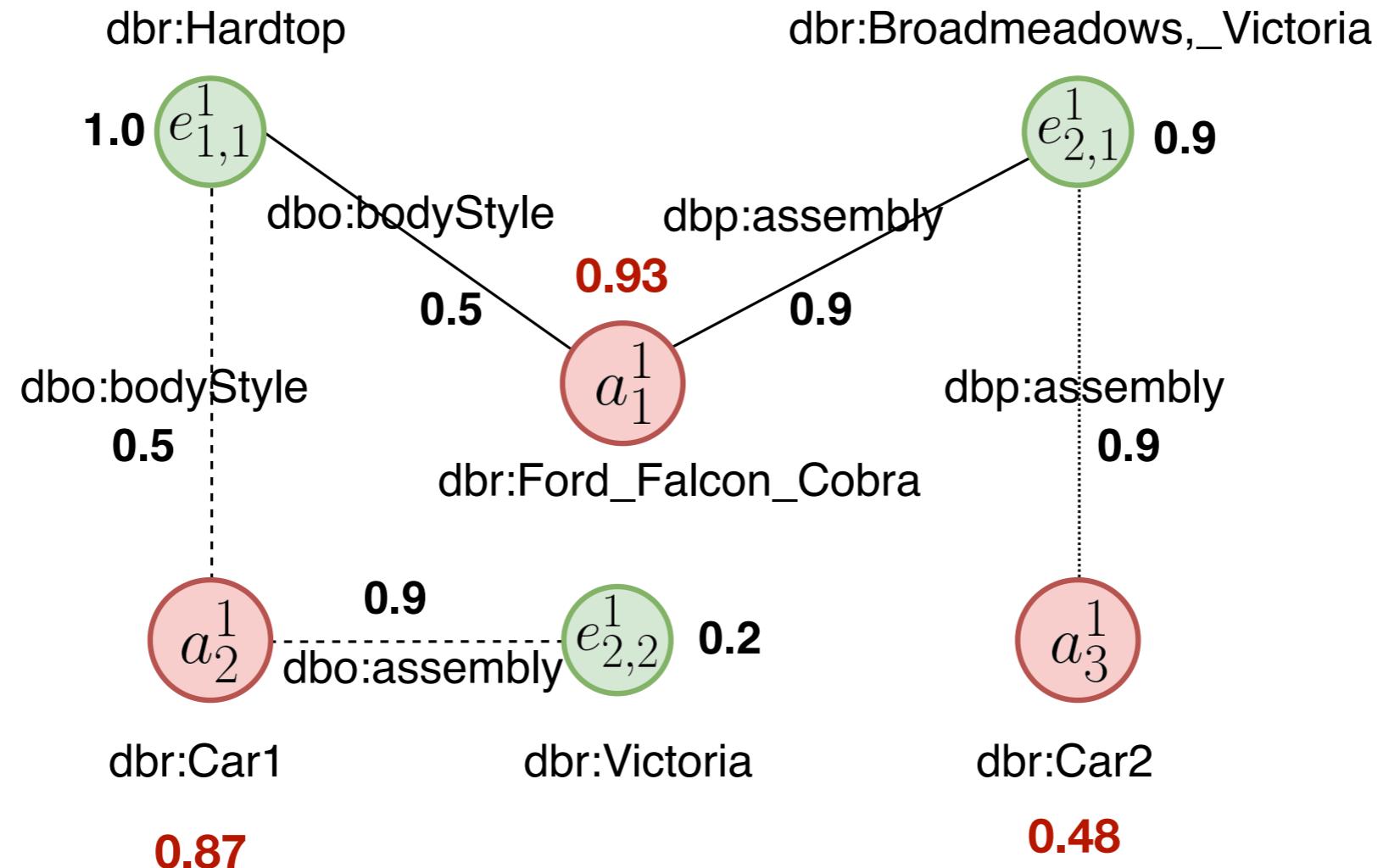
Which **hardtop** car is assembled in **Broadmeadows, Victoria**?



| | W | Ae | Ap | Ne | Np |
|----------------------------------|-------------|-------------|-------------|-----------|-----------|
| $(0.66 + 2 + 2) / (2 + 2 + 1) =$ | 0.93 | | | | |
| $(0.34 + 2 + 2) / (2 + 2 + 1) =$ | | 0.87 | | | |
| $(0.41 + 1 + 1) / (2 + 2 + 1) =$ | | | 0.48 | | |

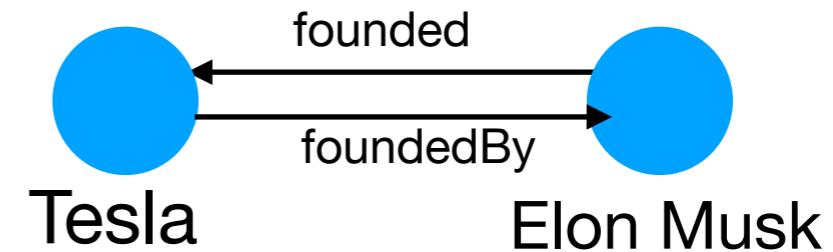
Aggregation: Score Normalization

Which **hardtop** car is assembled in **Broadmeadows, Victoria**?



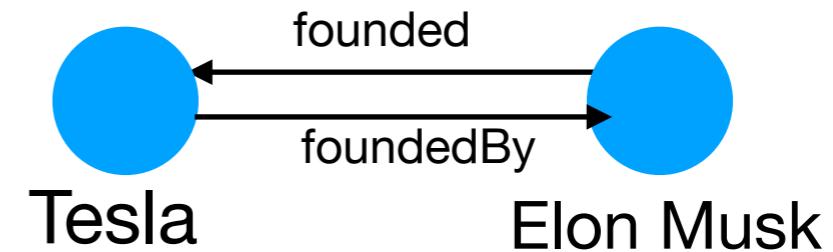
Limitations

- Directionality
 - Where is the **founder** of Tesla born?

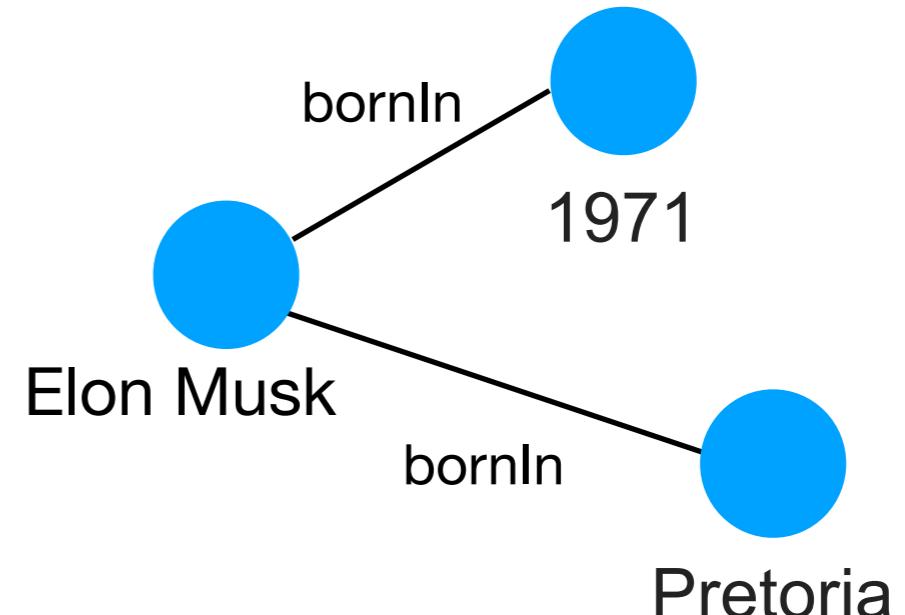


Limitations

- Directionality
 - Where is the **founder** of Tesla born?



- Property matching
 - Where is the founder of Tesla born?

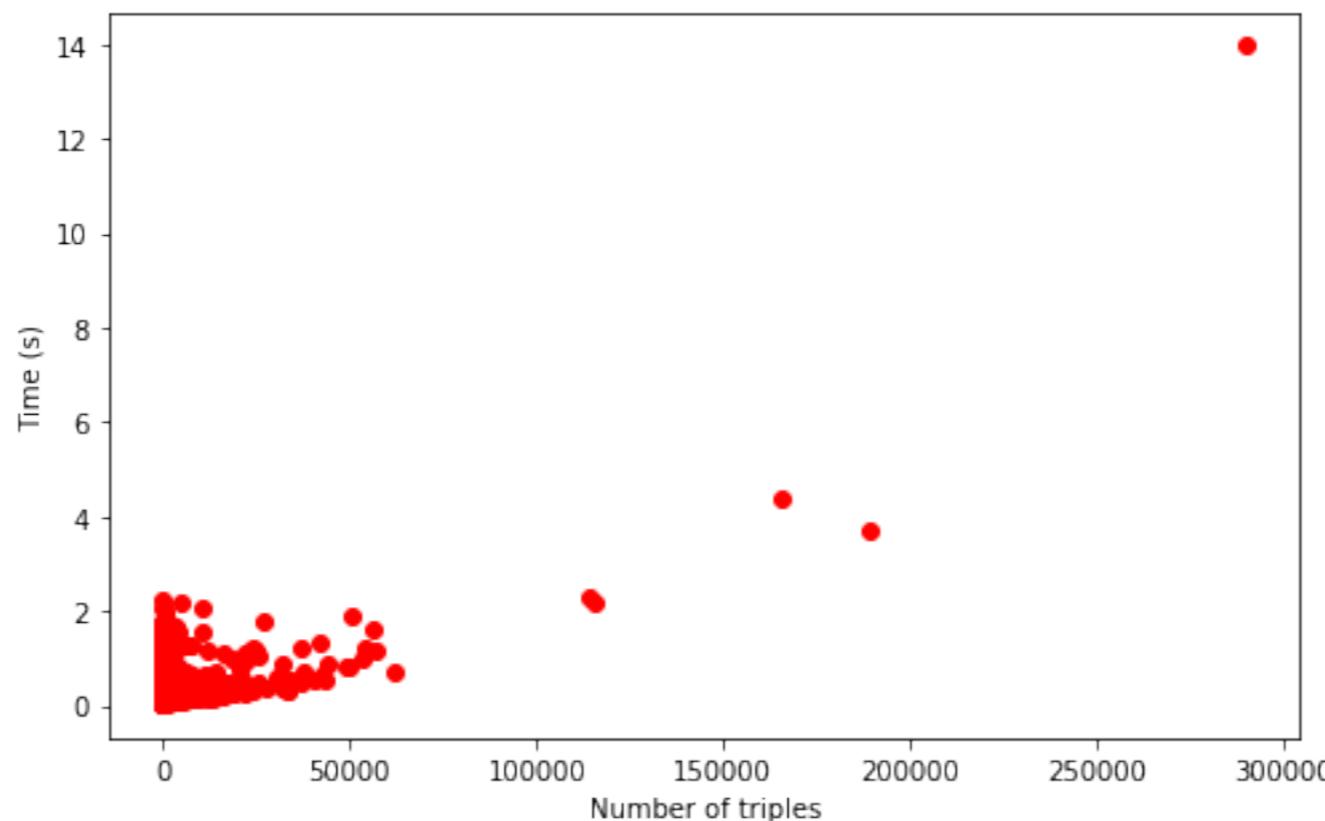


Results: Scalability

| Approach | P | R | F | Runtime |
|---------------------|-------|------|------|----------|
| WDAqua | 0.22* | 0.38 | 0.28 | 1.50 s/q |
| QAmp (our approach) | 0.25 | 0.50 | 0.33 | 0.72 s/q |

Results: Scalability

| Approach | P | R | F | Runtime |
|---------------------|-------|------|------|----------|
| WDAqua | 0.22* | 0.38 | 0.28 | 1.50 s/q |
| QAmp (our approach) | 0.25 | 0.50 | 0.33 | 0.72 s/q |



Results: Analysis

| Setup | Question interpretation | | | | P | R | F | Questions with errors | | | | | |
|-----------------------------------|-------------------------|----------------------|----------------------|----------------------|------|------|------|-----------------------|------------|---------------|--|--|--|
| | Q. type | Entity | Property | Class | | | | Total | New errors | | | | |
| | | | | | | | | | No match | Other→Revised | | | |
| 1 Question model* | | | GT | | 0.97 | 0.99 | 0.98 | 9% | – | 9% → 5% | | | |
| 2 Question type | PR | | GT | | 0.96 | 0.98 | 0.97 | 10% | – | 1% → 1% | | | |
| 3 Ignore classes | | GT | | None | 0.94 | 0.99 | 0.96 | 14% | – | 5% → 3% | | | |
| 4 Classes GT span ⁺ | | GT | | GT span ⁺ | 0.89 | 0.92 | 0.90 | 17% | 8% | – | | | |
| 5 Entities GT span ⁺ | GT | GT span ⁺ | | GT | 0.85 | 0.88 | 0.86 | 20% | 10% | 1% → 1% | | | |
| 6 Entities PR | GT | PR | | GT | 0.64 | 0.74 | 0.69 | 46% | 27% | 10% → 5% | | | |
| 7 Predicates GT span ⁺ | GT | | GT span ⁺ | GT | 0.56 | 0.59 | 0.57 | 48% | 34% | 5% → 3% | | | |
| 8 Predicates PR | GT | | PR | GT | 0.36 | 0.53 | 0.43 | 74% | 34% | 31% → 19% | | | |

Results: Analysis

| Setup | Question interpretation | | | | P | R | F | Questions with errors | | | | | |
|-----------------------------------|-------------------------|----------------------|----------|----------------------|------|------|------|-----------------------|------------|---------------|--|--|--|
| | Q. type | Entity | Property | Class | | | | Total | New errors | | | | |
| | | | | | | | | | No match | Other→Revised | | | |
| 1 Question model* | | | GT | | 0.97 | 0.99 | 0.98 | 9% | – | 9% → 5% | | | |
| 2 Question type | PR | | GT | | 0.96 | 0.98 | 0.97 | 10% | – | 1% → 1% | | | |
| 3 Ignore classes | | GT | | None | 0.94 | 0.99 | 0.96 | 14% | – | 5% → 3% | | | |
| 4 Classes GT span ⁺ | | GT | | GT span ⁺ | 0.89 | 0.92 | 0.90 | 17% | 8% | – | | | |
| 5 Entities GT span ⁺ | GT | GT span ⁺ | | GT | 0.85 | 0.88 | 0.86 | 20% | 10% | 1% → 1% | | | |
| 6 Entities PR | GT | PR | | GT | 0.64 | 0.74 | 0.69 | 46% | 27% | 10% → 5% | | | |
| 7 Predicates GT span ⁺ | GT | GT span ⁺ | GT | GT | 0.56 | 0.59 | 0.57 | 48% | 34% | 5% → 3% | | | |
| 8 Predicates PR | GT | PR | GT | GT | 0.36 | 0.53 | 0.43 | 74% | 34% | 31% → 19% | | | |

Results: Analysis

| Setup | Question interpretation | | | | P | R | F | Questions with errors | | | | | |
|-----------------------------------|-------------------------|----------------------|----------------------|----------------------|------|------|------|-----------------------|------------|---------------|--|--|--|
| | Q. type | Entity | Property | Class | | | | Total | New errors | | | | |
| | | | | | | | | | No match | Other→Revised | | | |
| 1 Question model* | | | GT | | 0.97 | 0.99 | 0.98 | 9% | – | 9% → 5% | | | |
| 2 Question type | PR | | GT | | 0.96 | 0.98 | 0.97 | 10% | – | 1% → 1% | | | |
| 3 Ignore classes | | GT | | None | 0.94 | 0.99 | 0.96 | 14% | – | 5% → 3% | | | |
| 4 Classes GT span ⁺ | | GT | | GT span ⁺ | 0.89 | 0.92 | 0.90 | 17% | 8% | – | | | |
| 5 Entities GT span ⁺ | GT | GT span ⁺ | | GT | 0.85 | 0.88 | 0.86 | 20% | 10% | 1% → 1% | | | |
| 6 Entities PR | GT | PR | | GT | 0.64 | 0.74 | 0.69 | 46% | 27% | 10% → 5% | | | |
| 7 Predicates GT span ⁺ | GT | | GT span ⁺ | GT | 0.56 | 0.59 | 0.57 | 48% | 34% | 5% → 3% | | | |
| 8 Predicates PR | GT | | PR | GT | 0.36 | 0.53 | 0.43 | 74% | 34% | 31% → 19% | | | |

Acknowledgements

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*PROJECT OPEN DATA FOR LOCAL COMMUNITIES FUNDED BY THE
AUSTRIAN FEDERAL MINISTRY OF TRANSPORT, INNOVATION AND
TECHNOLOGY (BMVIT) UNDER THE PROGRAM "ICT OF THE FUTURE",
BETWEEN NOVEMBER 2016 AND APRIL 2019.*

MORE INFORMATION [HTTPS://IKTDERZUKUNFT.AT/EN/](https://iktderzukunft.at/en/)



*Austrian Ministry
for Transport,
Innovation and Technology*