KATHOLIEKE UNIVERSITEIT LEUVEN

DTAI
MACHINE LEARNING

DTProbLog

A Decision-Theoretic Probabilistic Prolog

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Motivation

- Many real-world decision problems are relational and probabilistic
  - Wildfire control
  - Who to vaccinate for swine flu
  - Viral marketing
  - ...

Motivation

- Combination of **relations**, **uncertainty** and **decision theory** largely ignored

  some exceptions are MLDNs, DTLPs and FOMDPs

- Relations with uncertainty

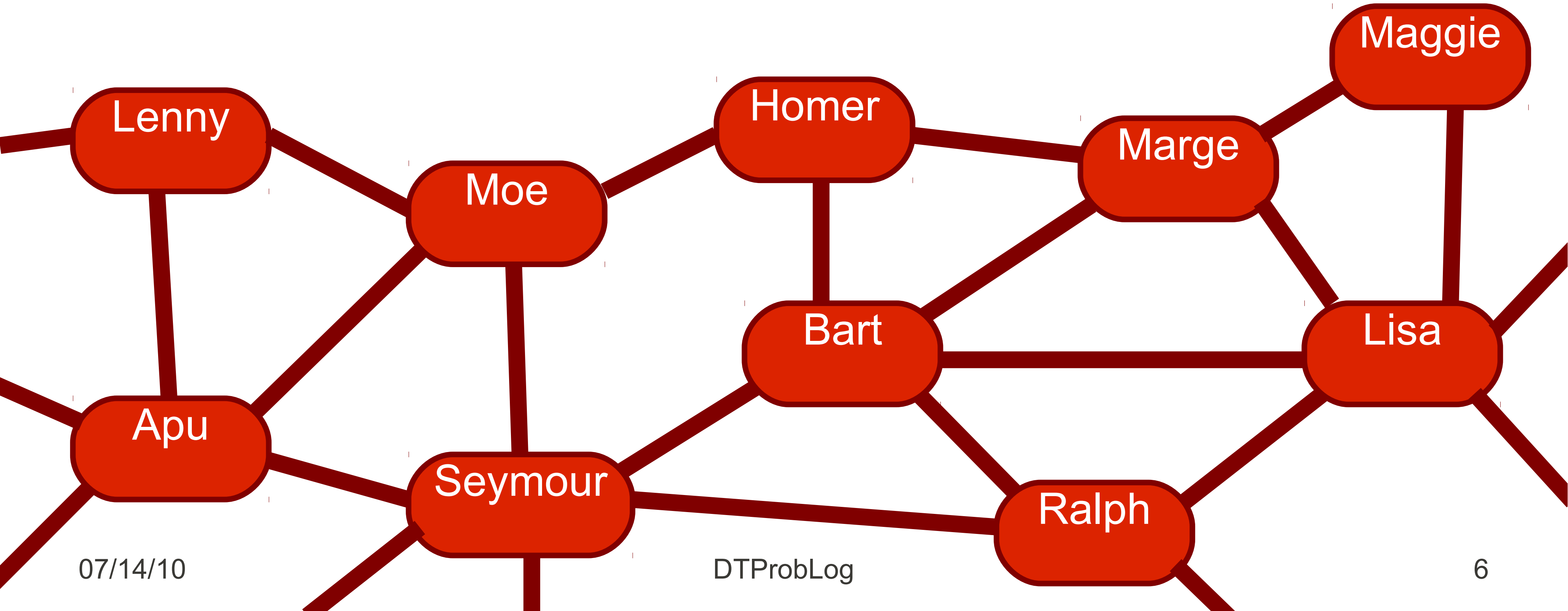
  = **S**tatistical **R**elational **L**earning

- ProbLog is a simple **probabilistic** Prolog
- DTProbLog is a **decision-theoretic** ProbLog

Outline

- DTProbLog: the Language
- DTProbLog: the Algorithms
    - Exact Solution Algorithm
    - Approximate Solution Algorithms
- Experiments: Viral Marketing
- Related Work & Conclusions

DTProbLog: the Language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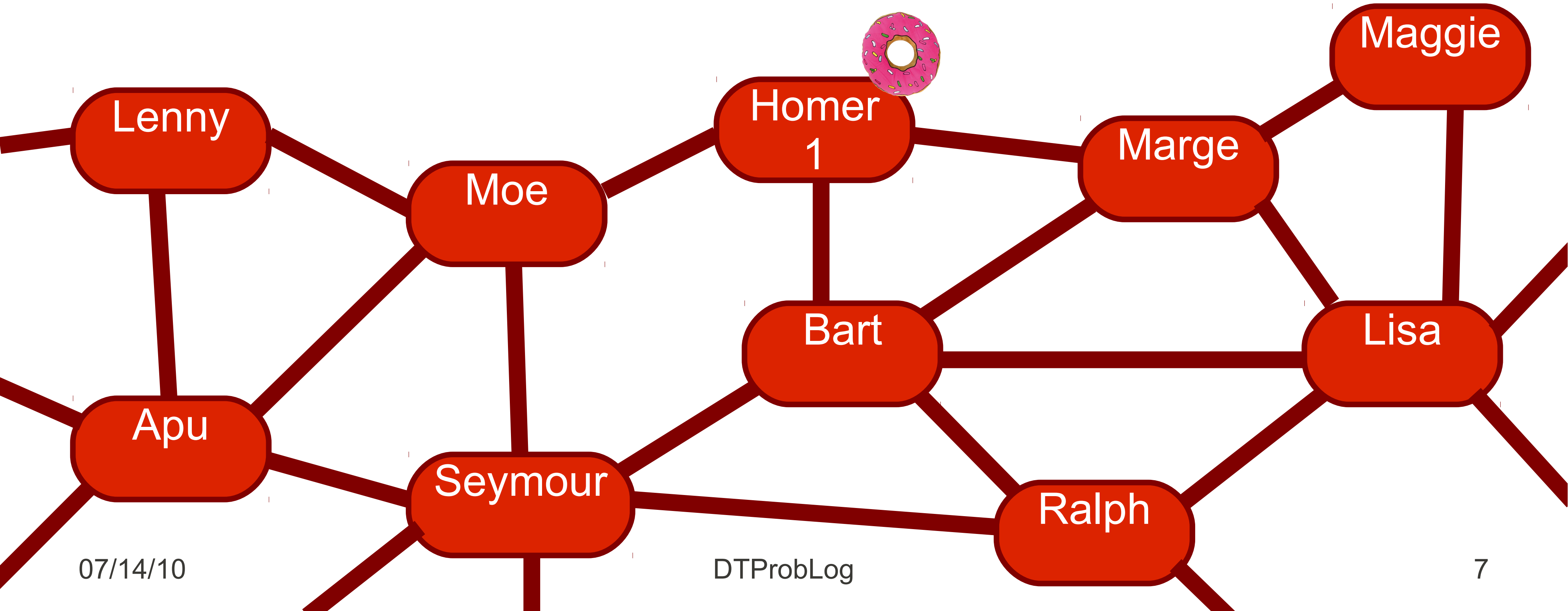
Ralph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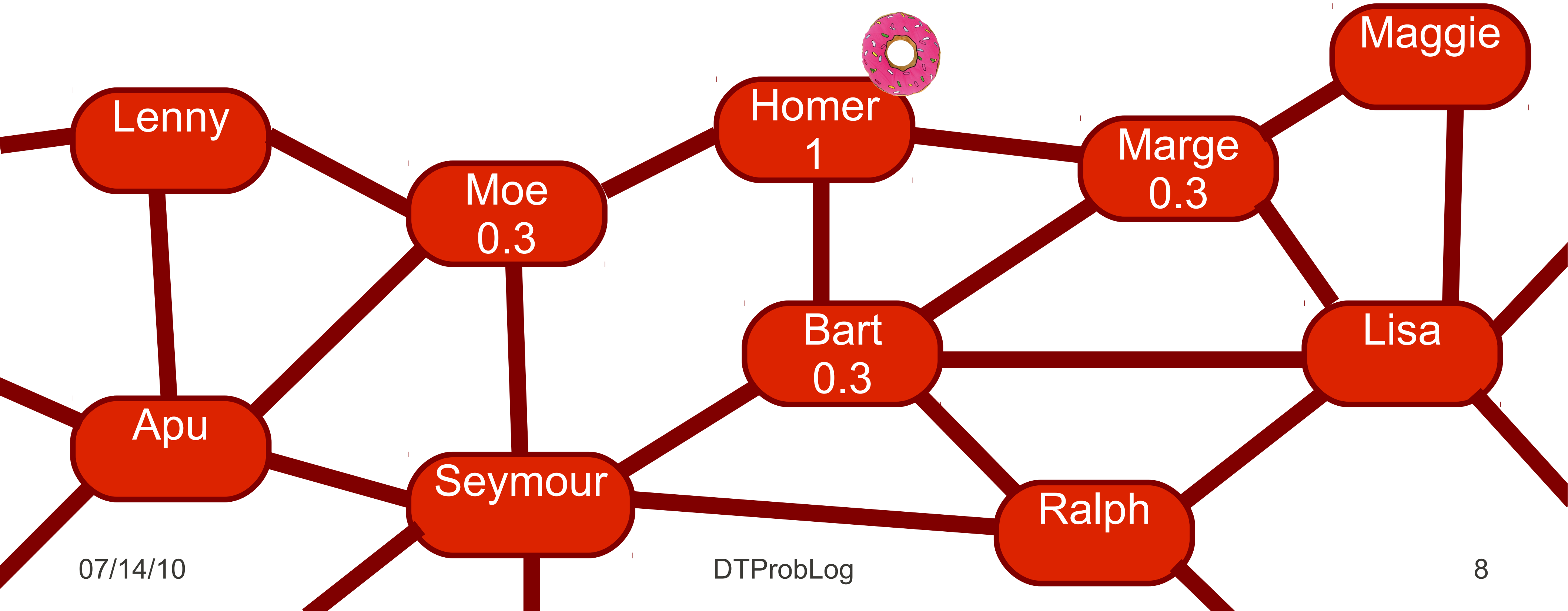
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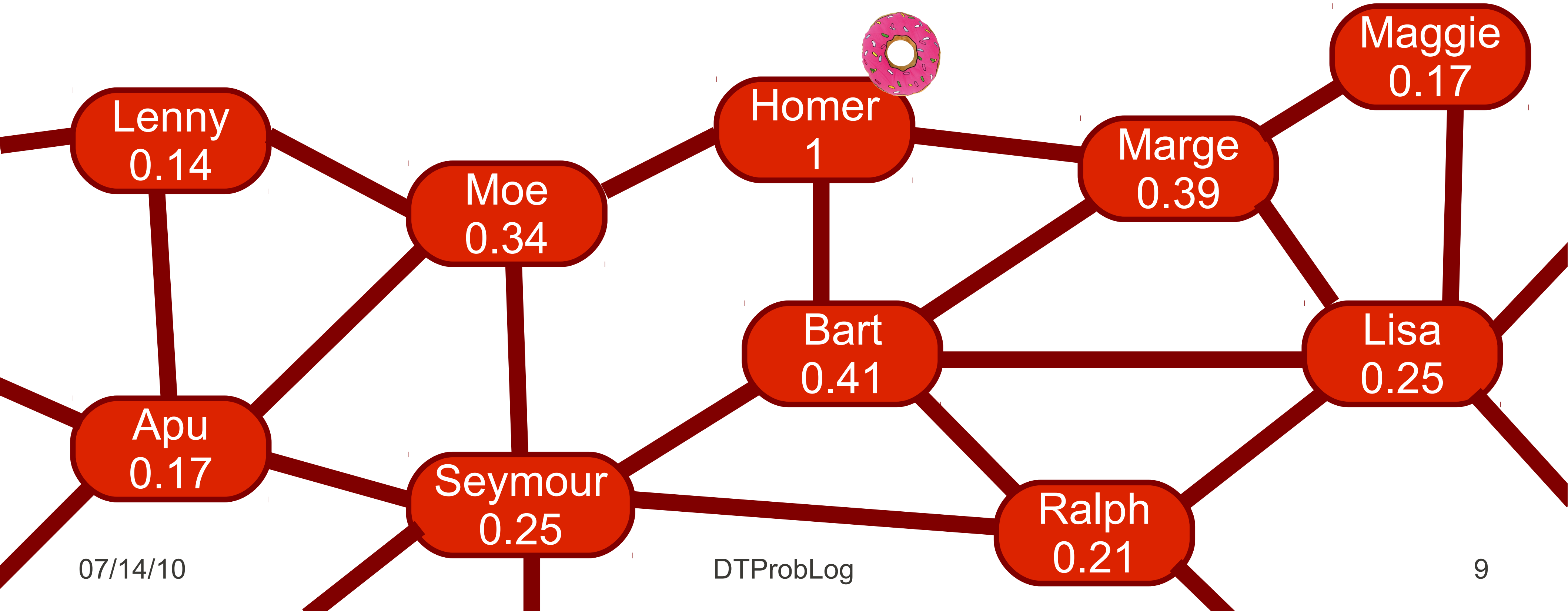
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0.17
Seymour
0.25
Ralph
0.21

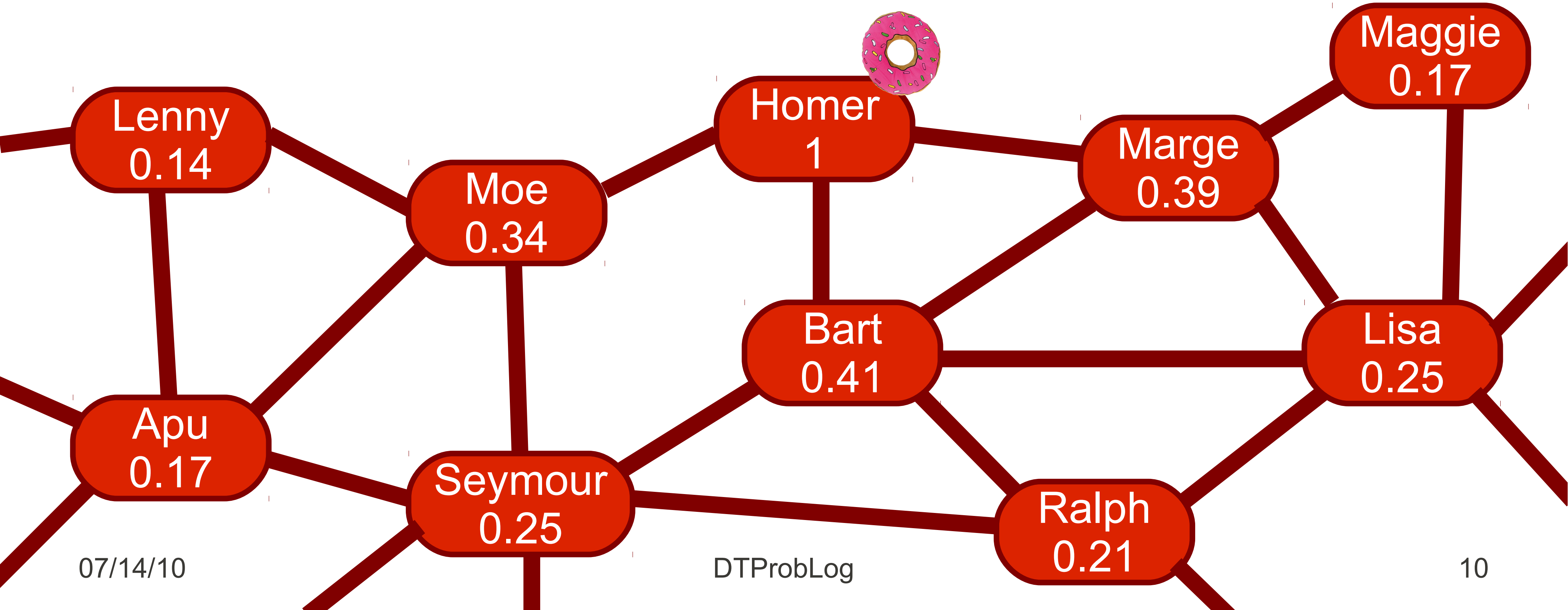
ProbLog

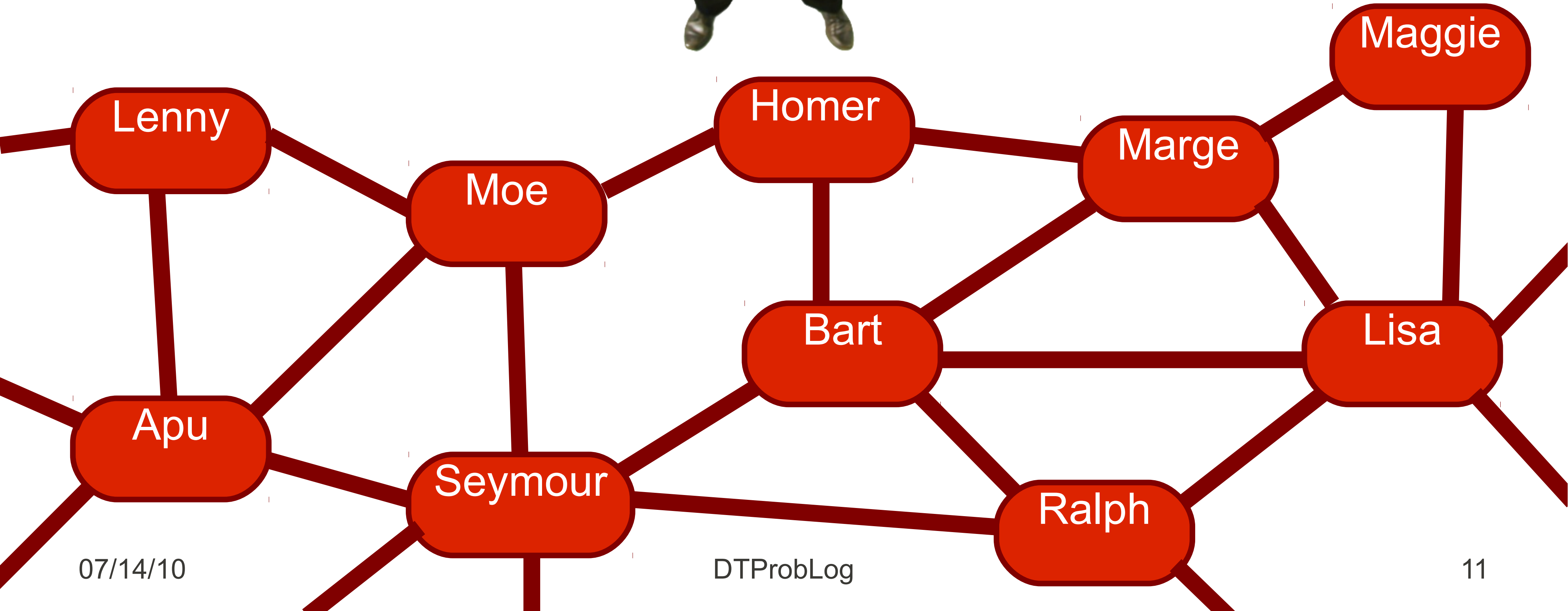
Probabilistic Facts

```
0.3 :: buy_trust(_,_).
```

Background Knowledge

```
buys(X) :-
     trusts(X,Y),
     buys(Y),
     buy_trust(X,Y).
```

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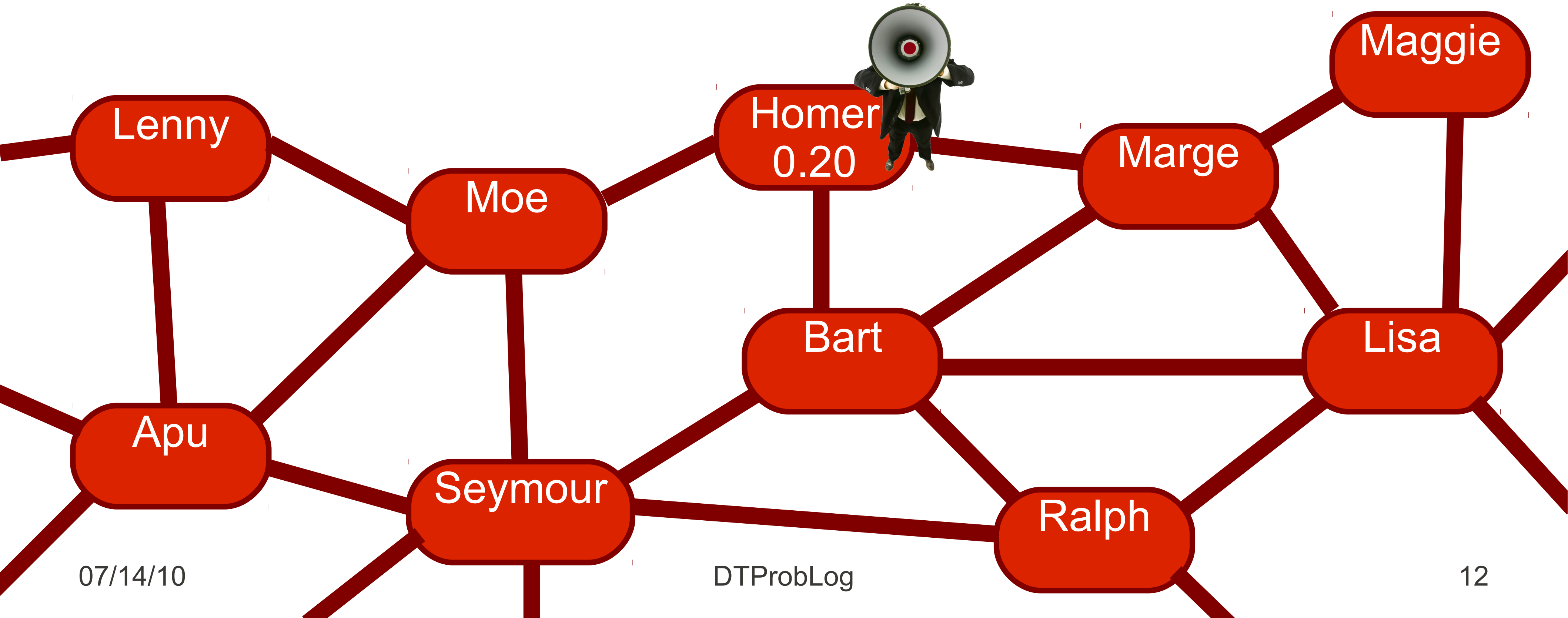
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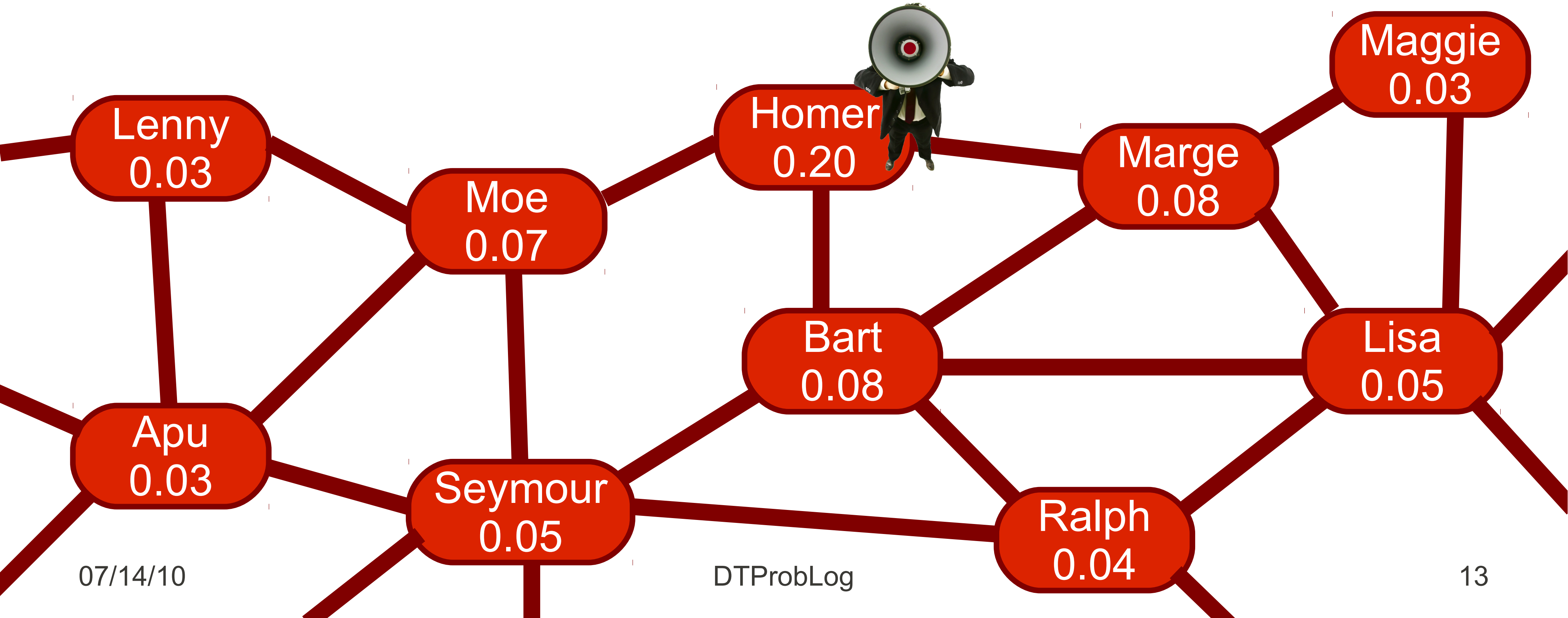
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0.05
Apu
0.03
Seymour
0.05
Ralph
0.04

ProbLog

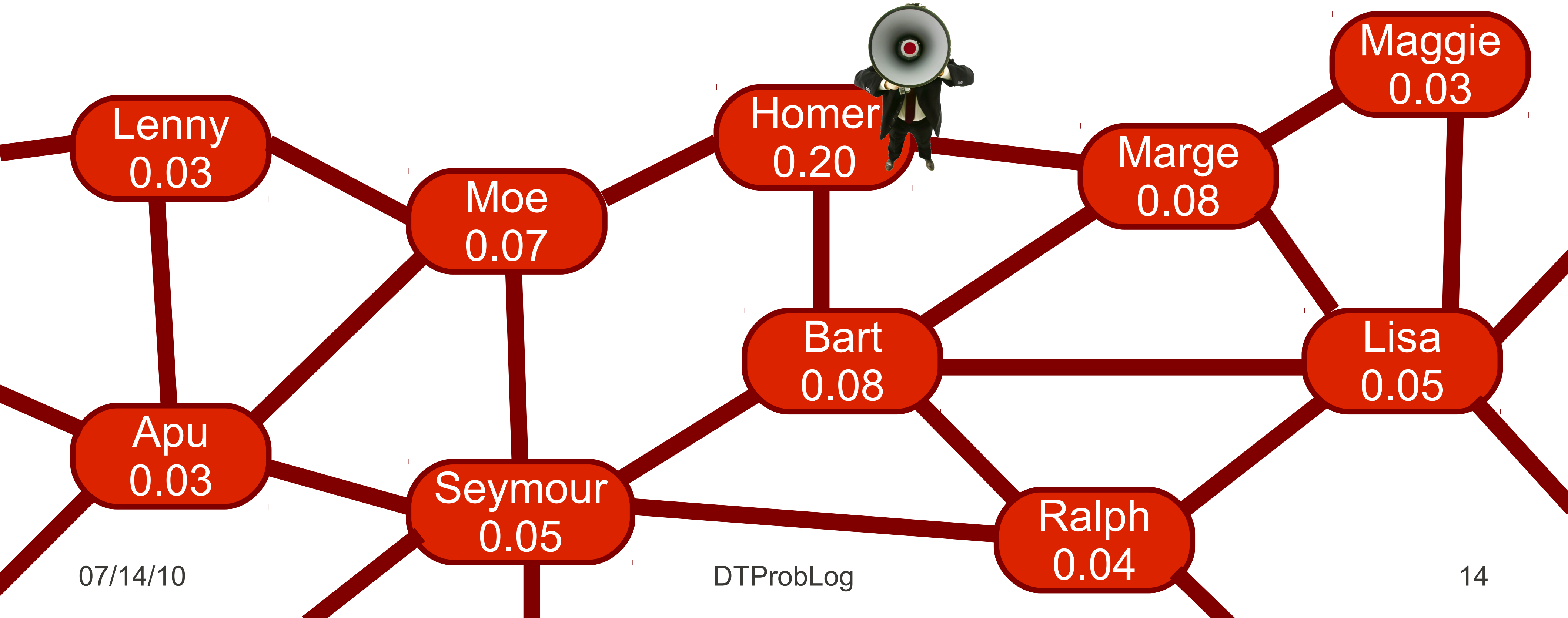
Probabilistic Facts

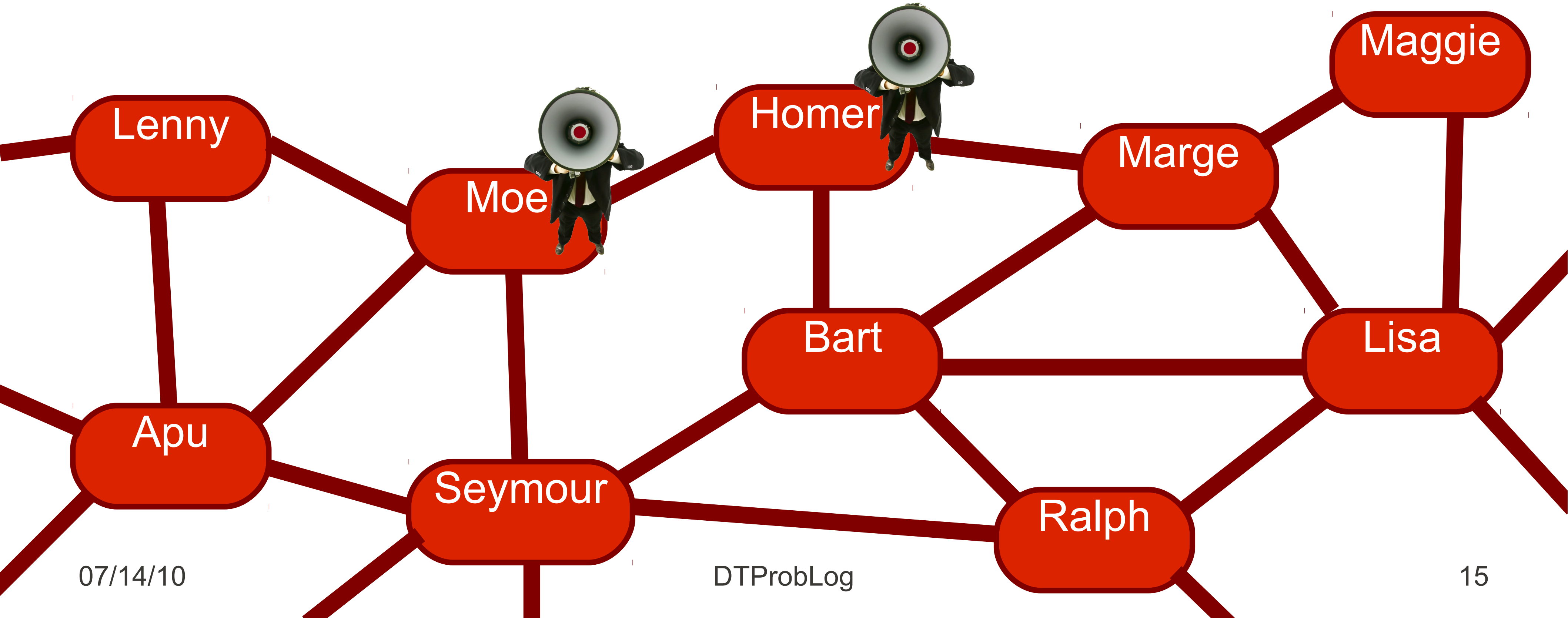
```
0.3 :: buy_trust(_,_).
0.2 :: buy_marketing(_).
```

Background Knowledge

```
buys(X) :-
      trusts(X,Y),
      buys(Y),
      buy_trust(X,Y).
```

```
buys(X) :-
      marketed(X),
      buy_marketing(X).
```

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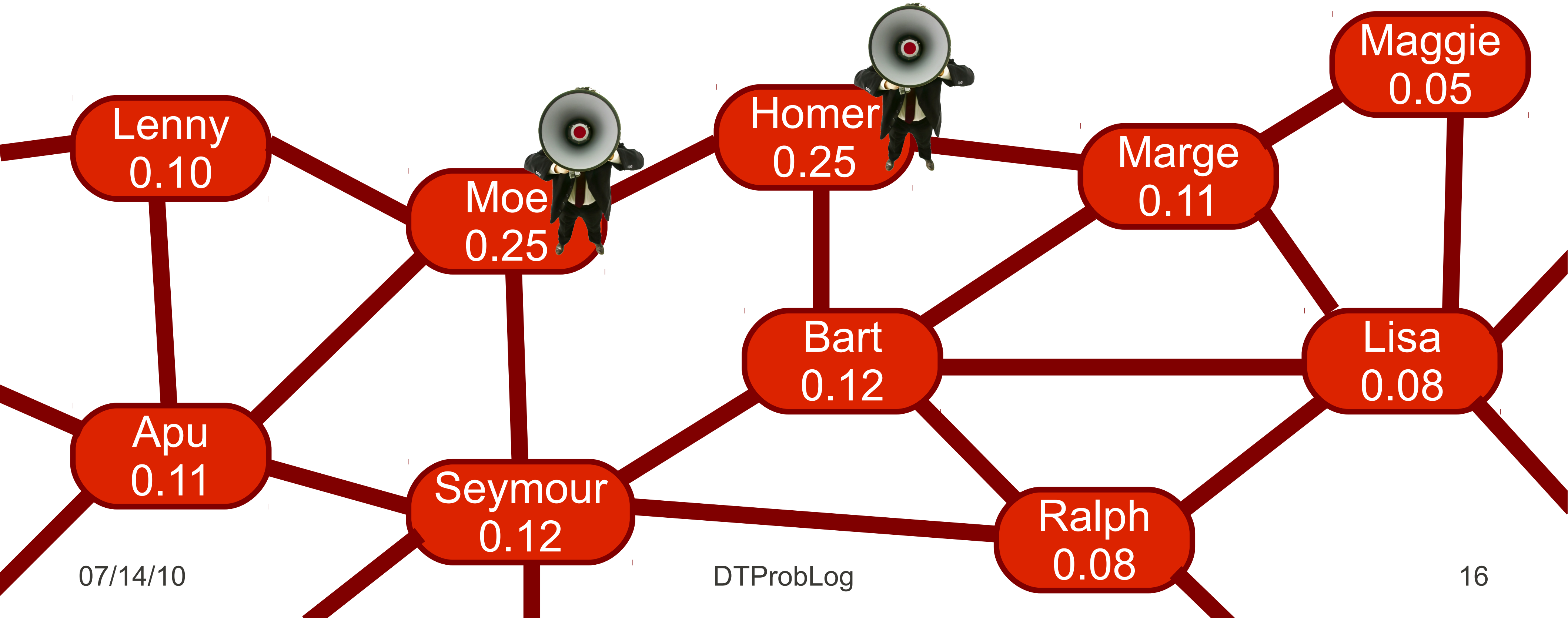
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Homer
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Maggie
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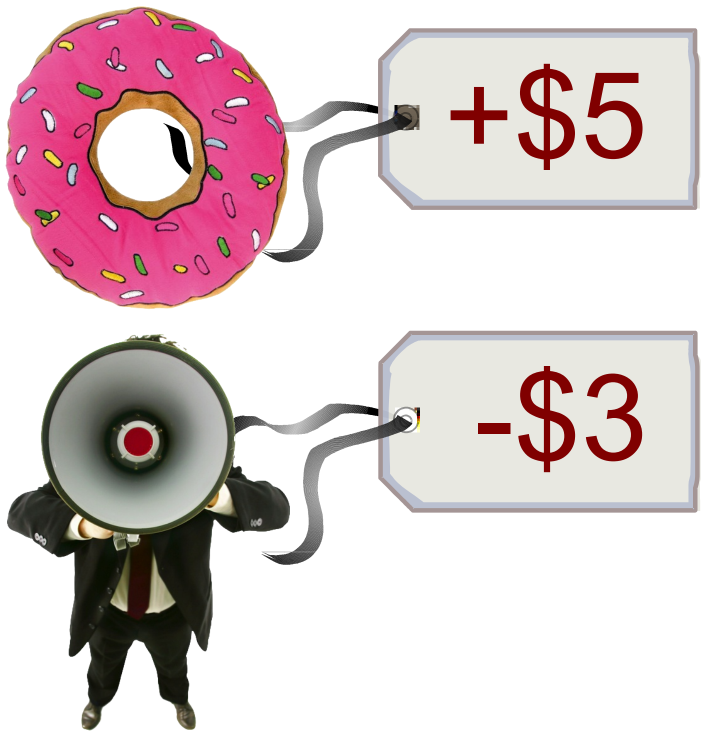
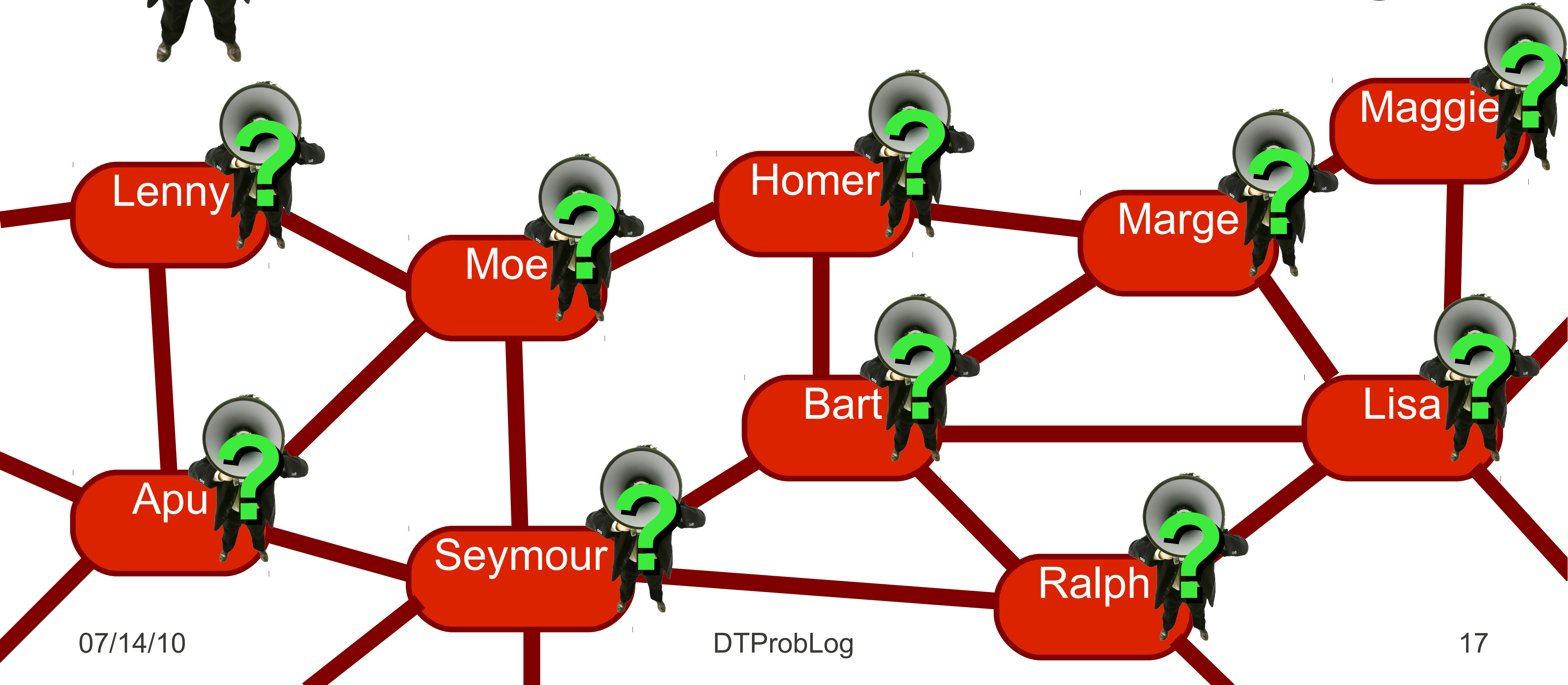
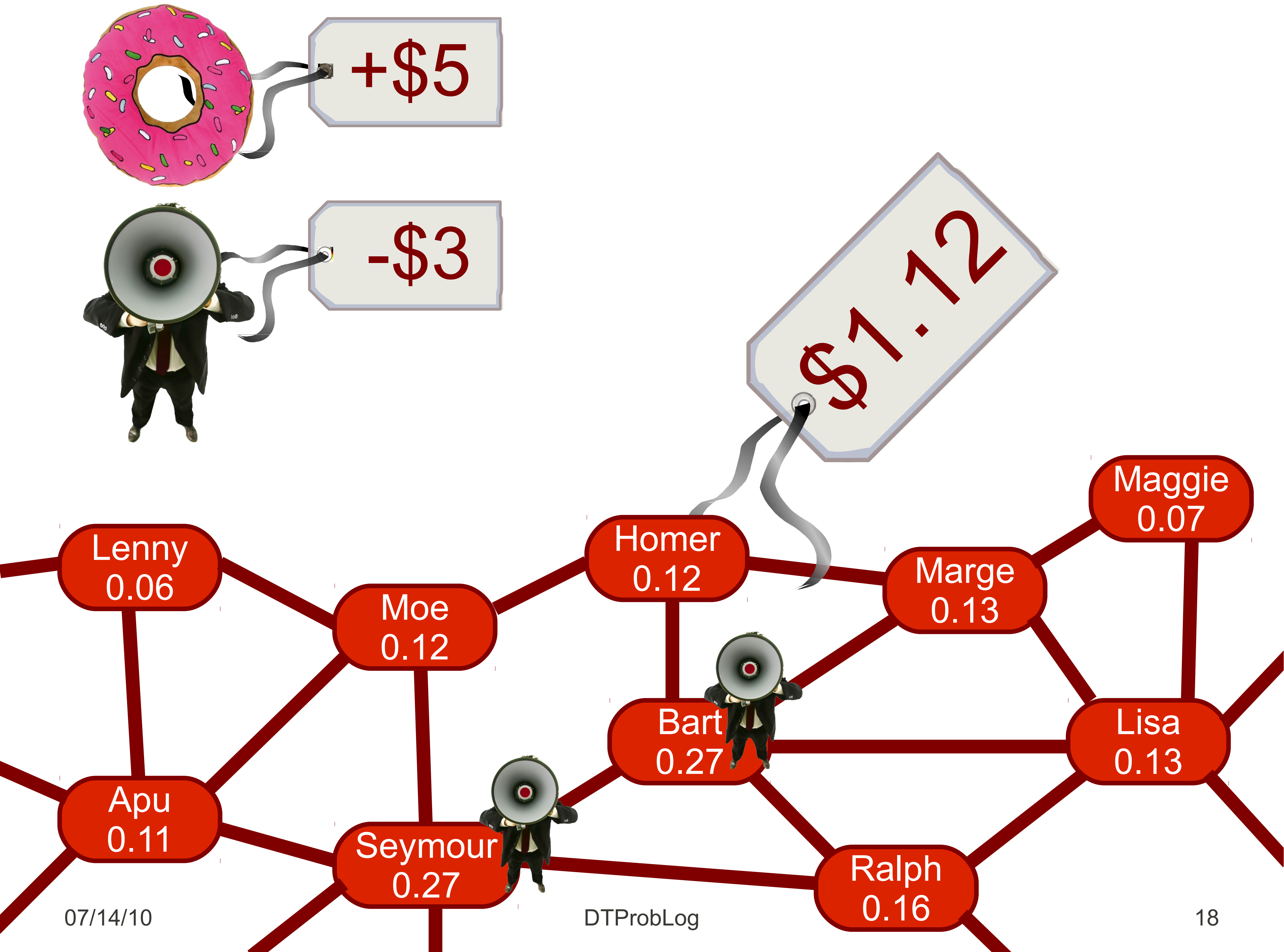
Apu
0.11
Seymour
0.12
Ralph
0.08



Which **strategy** gives the **maximum expected utility**?

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-$3
$1.12
Lenny 0.06
Moe 0.12
Homer 0.12
Marge 0.13
Maggie 0.07
Bart 0.27
Lisa 0.13
Apu 0.11
Seymour 0.27
Ralph 0.16

DTProbLog

Probabilistic Facts

...

Background Knowledge

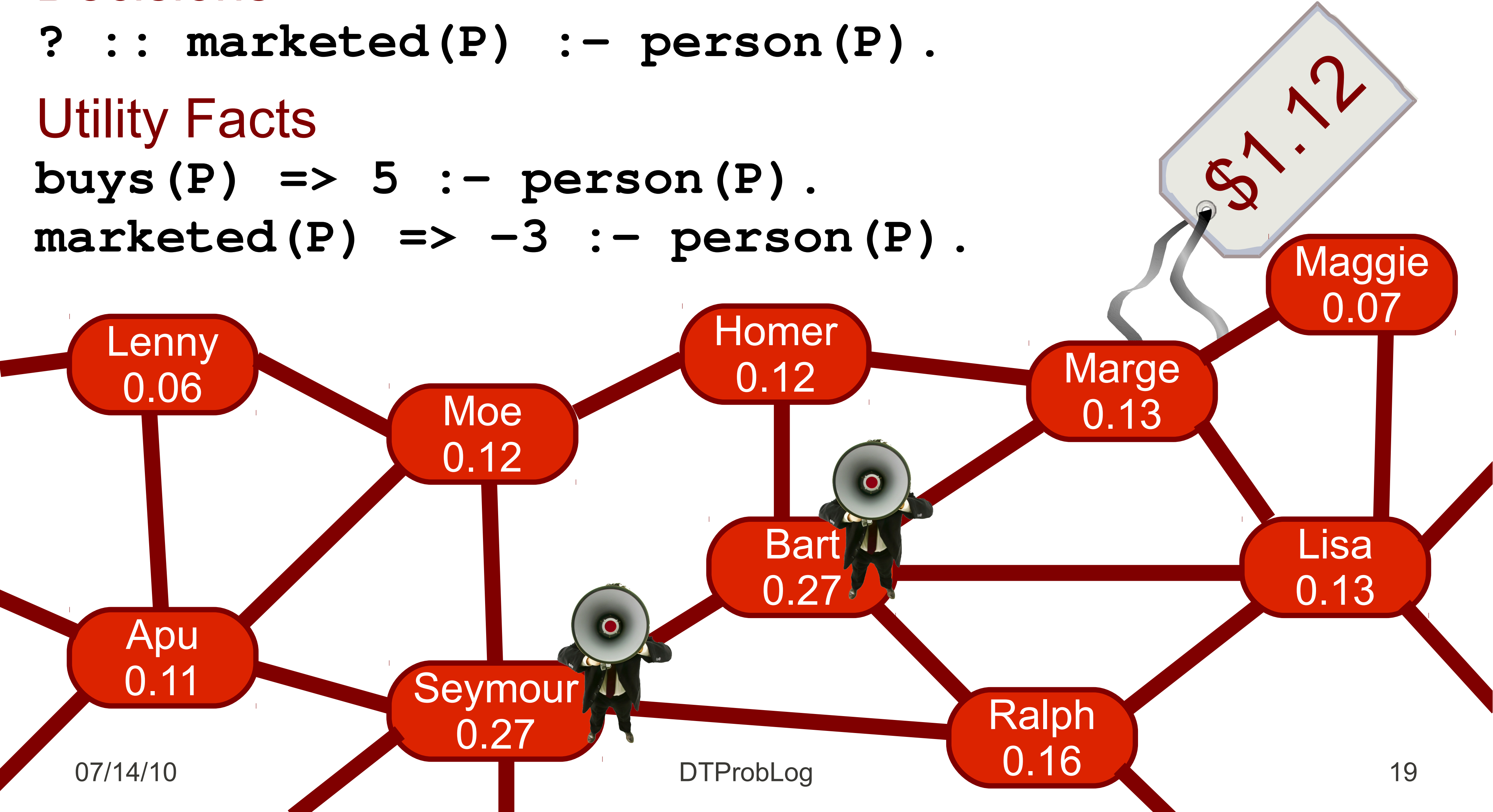
...

Decisions

```
? :: marketed(P) :- person(P).
```

Utility Facts

```
buys(P) => 5 :- person(P).
marketed(P) => -3 :- person(P).
```



DTProbLog: the Algorithms

DTProbLog: the Algorithms

- DTProbLog solves **decision** problems in complex **relational** and **uncertain** environments.
- Exact solution algorithm
  - Extends ProbLog's BDD-based inference
  - Efficient datastructures: BDD and ADD
- Approximate algorithms
  - Local search
  - K-best proofs

Example:
Dressing for unpredictable weather

Decision Facts

```
? :: umbrella.
? :: raincoat.
```

Probabilistic Facts

```
0.3 :: rainy.
0.5 :: windy.
```

Background Knowledge

```
dry :- rainy, umbrella, not(broken_umbrella).
dry :- rainy, raincoat.
dry :- not(rainy).

broken_umbrella :- umbrella, rainy, windy.
```

Utility Facts

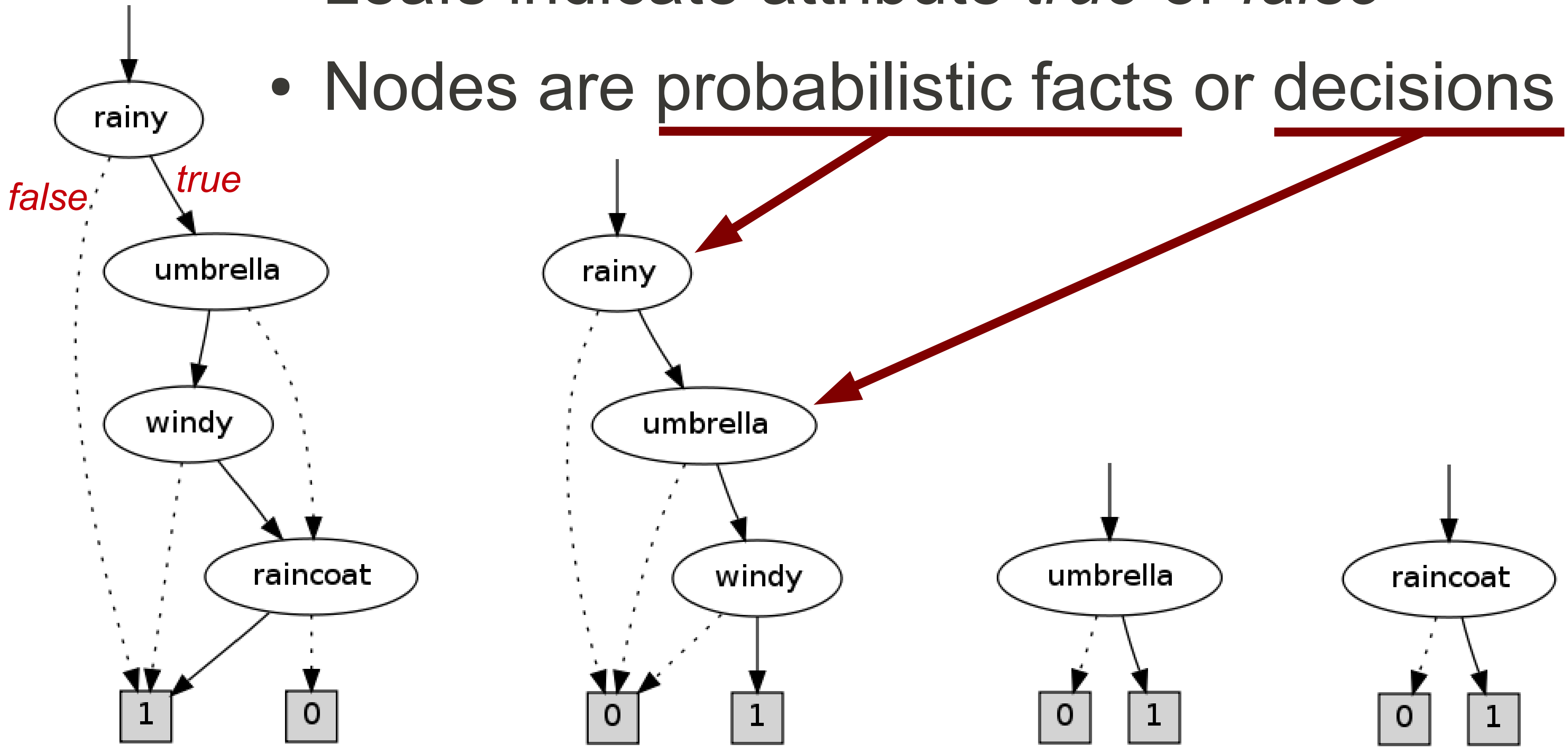
```
umbrella => -2.
raincoat => -20.
```

```
dry => 60.
broken_umbrella => -40.
```

Exact Solution Algorithm

1. Find all **proofs** for each utility attribute (Prolog)
2. Binary decision diagrams from the proofs
3. Algebraic decision diagrams for the **probability** of each attribute
4. Algebraic decision diagrams for the **utility** of each attribute
5. Algebraic decision diagram for the **total utility**

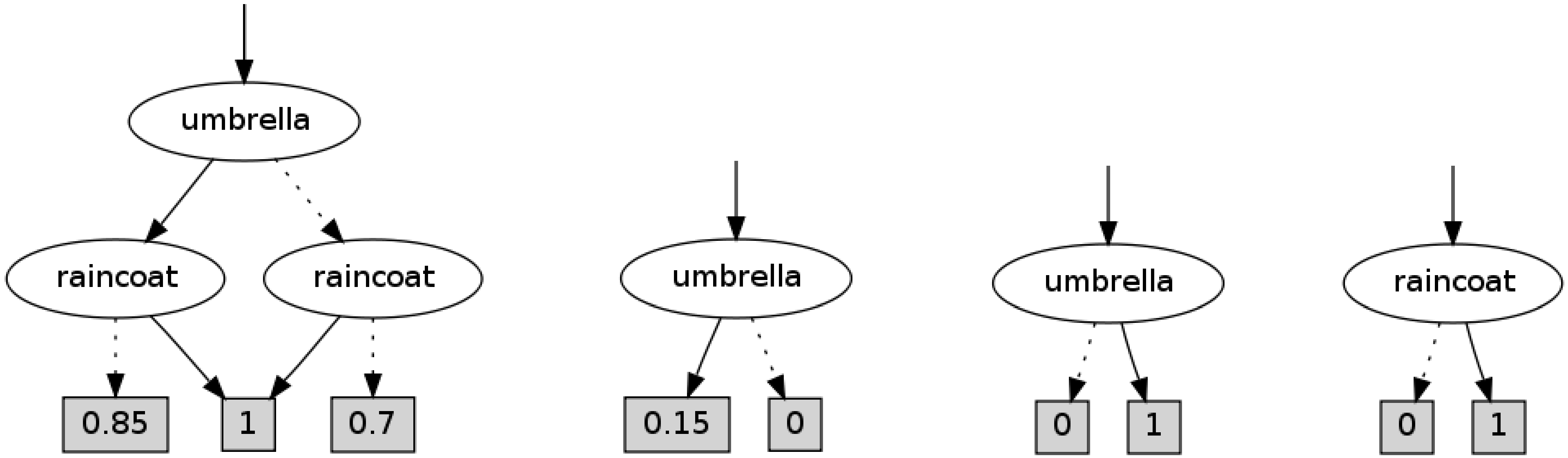
1. Find all **proofs** for each utility attribute (Prolog)
2. Binary decision diagrams from the proofs
   - Leafs indicate attribute *true* or *false*
   - Nodes are probabilistic facts or decisions



```
dry => 60.                     umbrella => -2.
        broken_umbrella => -40.    raincoat => -20.
```

3 Algebraic decision diagrams for the **probability** of each attribute

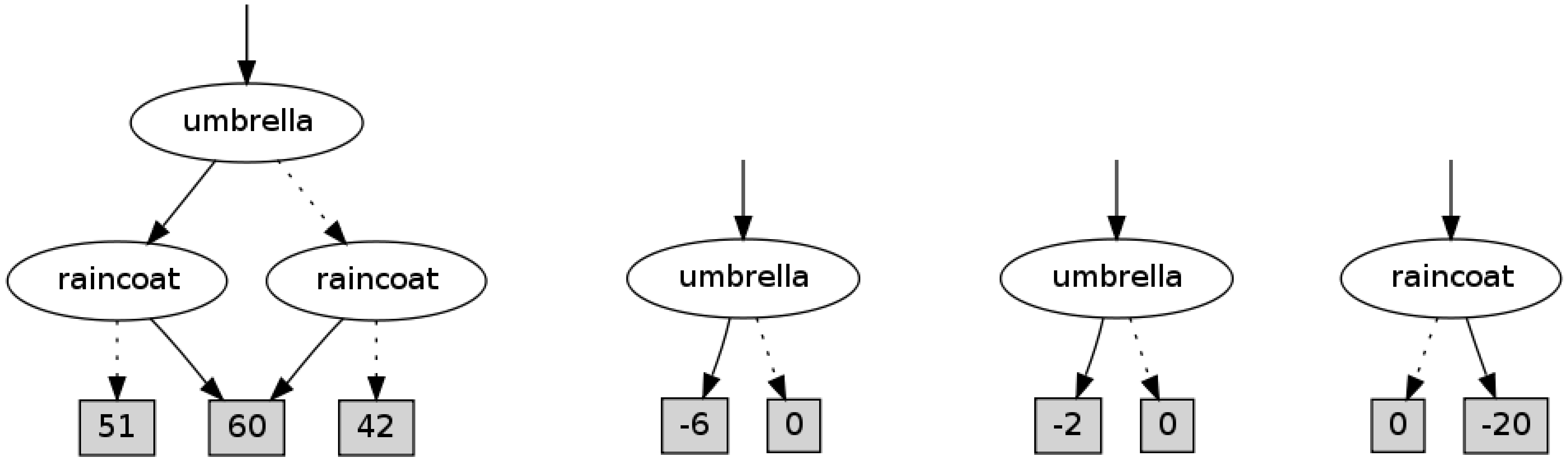
- Probabilistic facts are marginalized out
- Nodes are decisions only
- Leafs are probabilities



```
dry => 60.                        umbrella => -2.
         broken_umbrella => -40.     raincoat => -20.
```

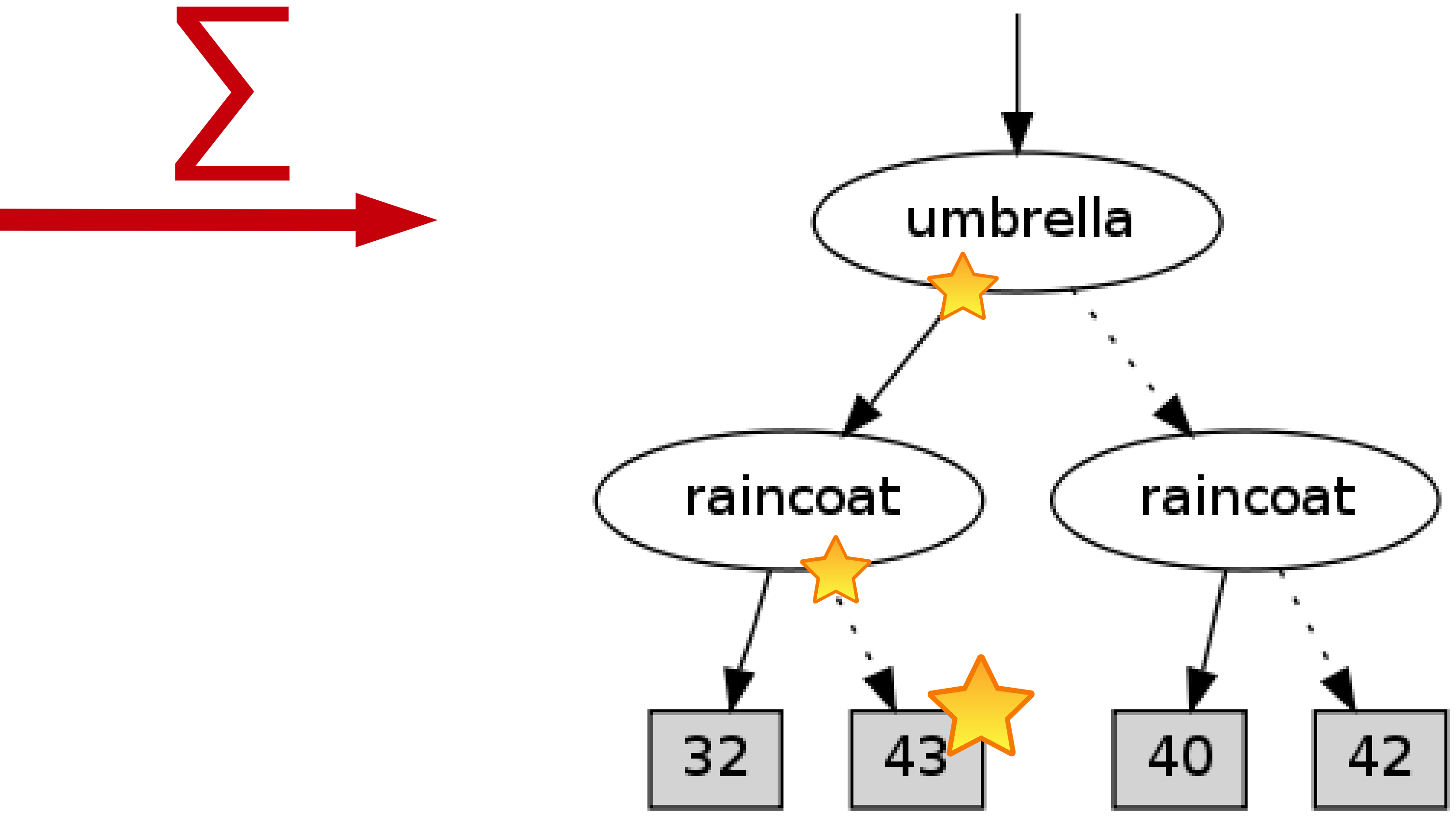
4 Algebraic decision diagrams for the **utility** of each attribute

- Leafs are expected utilities



```
dry => 60.                         umbrella => -2.
        broken_umbrella => -40.     raincoat => -20.
```

5 Algebraic decision diagram for the **total utility**



+ sound pruning (ADD not built entirely in memory)

Approximate Solution: Local Search

1. Find all **proofs** for each utility attribute (Prolog)
2. Binary decision diagrams from the proofs
3. Algebraic decision diagrams for the **probability** of each attribute
4. Algebraic decision diagrams for the **utility** of each attribute
5. Algebraic decision diagram for the **total utility**

Approximate Solution: Local Search

1. Find all **proofs** for each utility attribute (Prolog)
2. Binary decision diagrams from the proofs
3. ~~Algebraic decision diagrams for the **probability** of each attribute~~
4. ~~Algebraic decision diagrams for the **utility** of each attribute~~
5. ~~Algebraic decision diagram for the **total utility**~~

3 Greedy hillclimber search

Approximate Solution: K-best Proofs

1. Find all **proofs** for each utility attribute (Prolog)
2. Binary decision diagrams from the proofs
3. Algebraic decision diagrams for the **probability** of each attribute
4. Algebraic decision diagrams for the **utility** of each attribute
5. Algebraic decision diagram for the **total utility**

Approximate Solution: K-best Proofs

1 ~~Find all **proofs** for each utility attribute (Prolog)~~

1 Find the ***k* most likely** **proofs** for each utility attribute

2 Binary decision diagrams from the proofs

3 Algebraic decision diagrams for the **probability** of each attribute

4 Algebraic decision diagrams for the **utility** of each attribute

5 Algebraic decision diagram for the **total utility**

Experiments: Viral Marketing

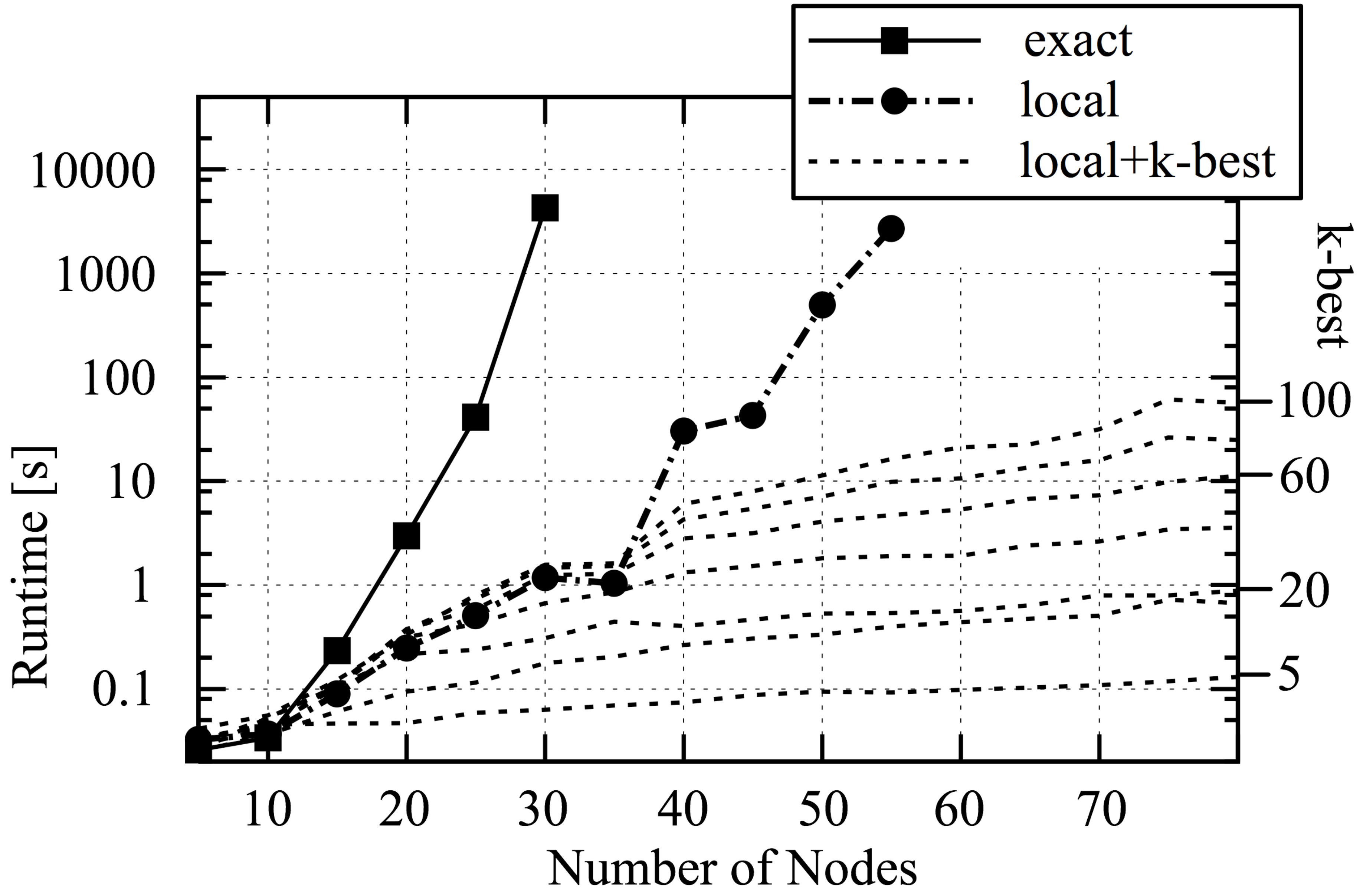
Experiments: Viral Marketing

- Synthetic dataset

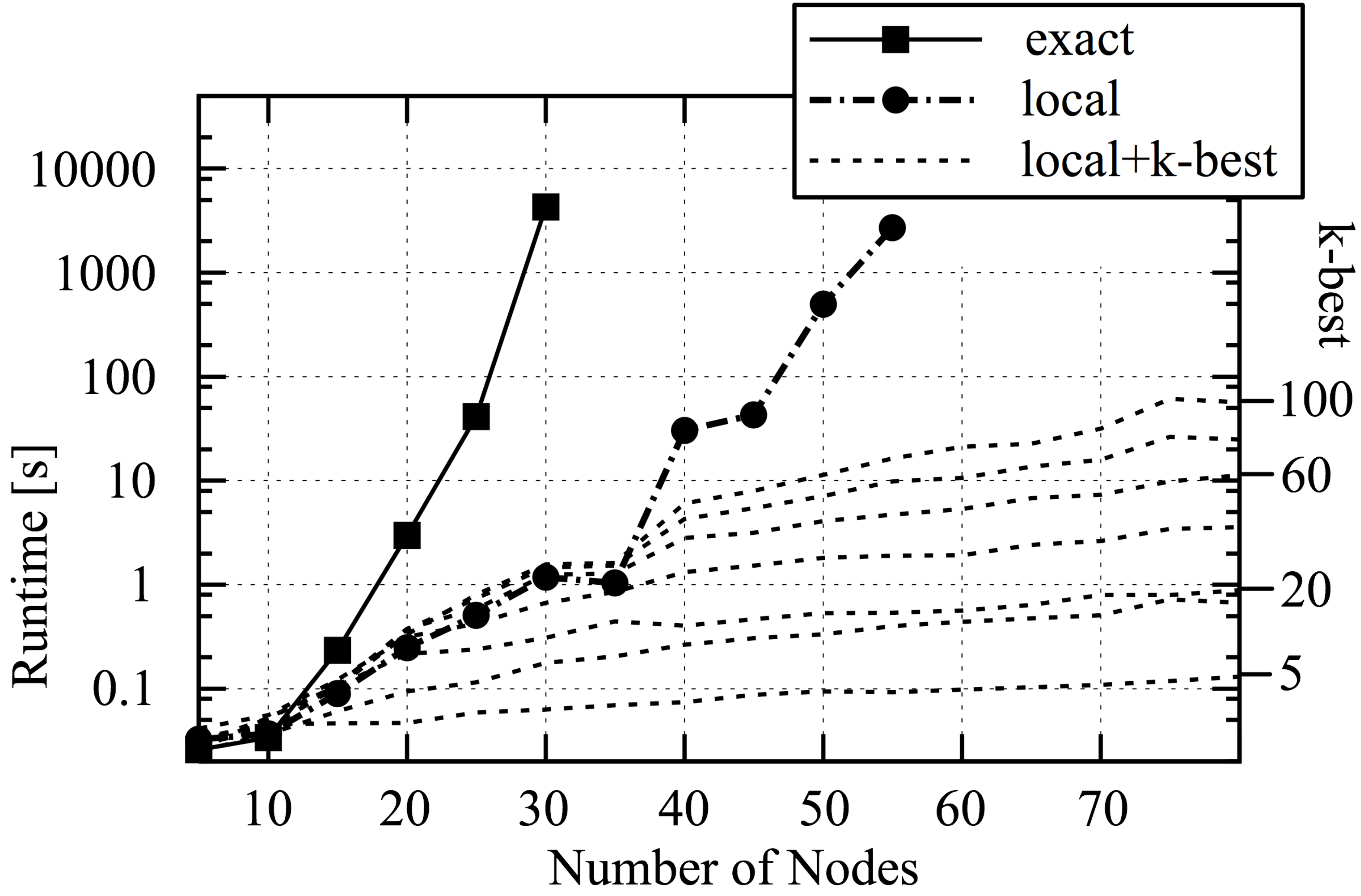
  Random power law graphs of increasing size

- Real-world Epinions dataset [Domingos02]

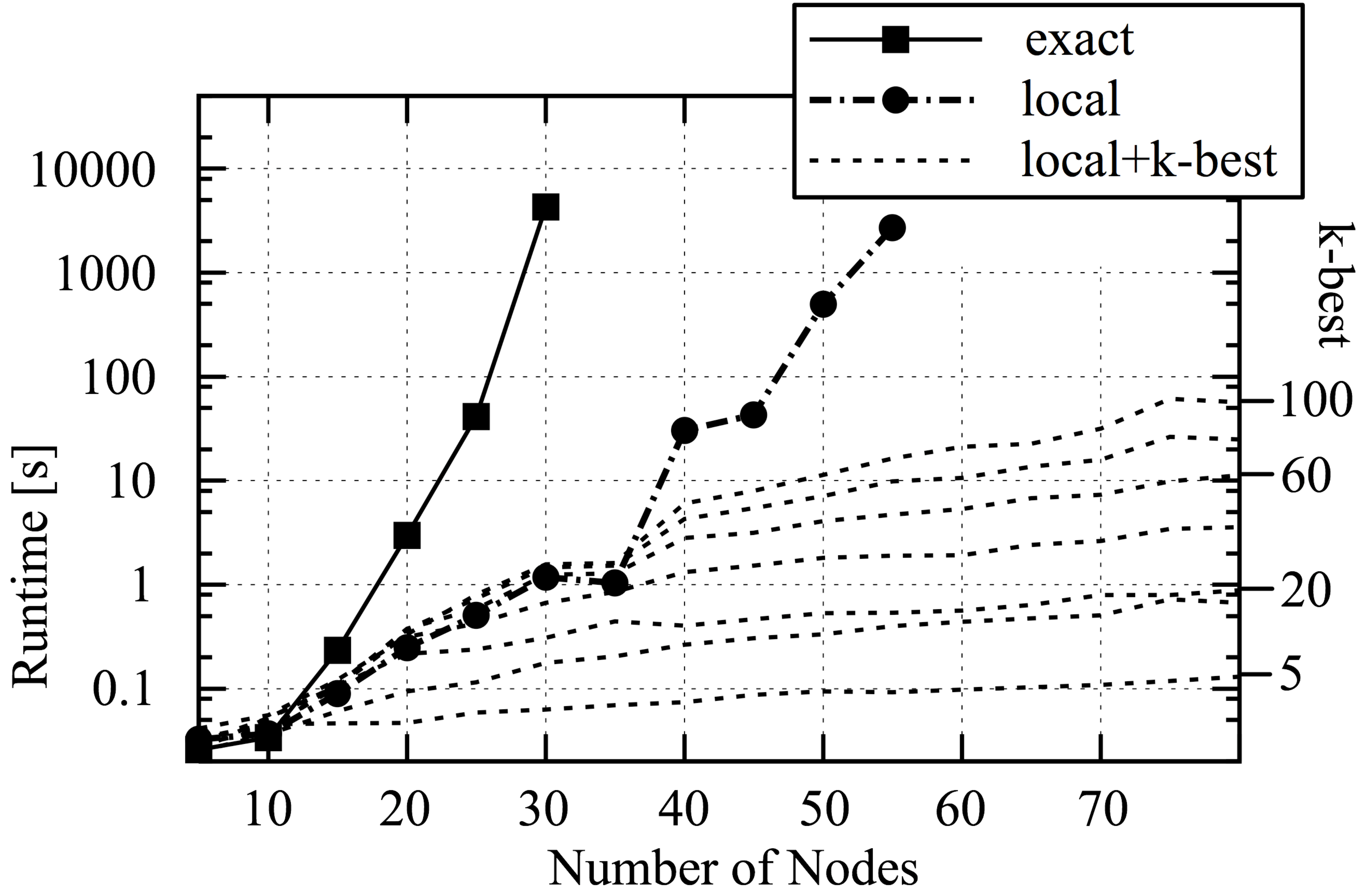
(Q1) Does the **exact** solution algorithm perform better than **naively** calculating the utility of all strategies?



(Q2) What is the difference in runtime and solution quality between **exact** and **local** search?



(Q3) What is the difference in runtime and solution quality between for different values of *k* in **k-best**.



(Q4) Do the algorithms **scale**?

Epinions social network

- 75,000 people
- 500,000 trust relations

YES

- Local search
- 17-best proofs
- Solved in 16 hours

Related Work & Conclusions

Related Work

	Representation		Solution		Evaluation	
	Relational	Probabilities	Global optimum	Local optimum	Exact inference	Approximate inference
Influence Diagrams		✓	✓	?	✓	✓
MLDNs [Nath]	✓	✓		✓		✓
ICL [Poole]	✓	✓	?	?	?	?
DTLPs [Chen]	✓	✓				
DTProbLog	✓	✓	✓	✓	✓	✓

Summary

- DTProbLog, the programming language
  - Probabilistic Prolog
  - Decisions
  - Utilities: rewards or costs attached to goals
- Solution algorithms
  - Exactly
  - Approximately
- Experiments
  - Effective
  - Scale well

Ongoing and Future Work

- Sequential decision problems
  - Easy to represented in DTProbLog
  - Bad fit for solution algorithms
- Solvers
  - Integer linear programming
  - Bounded approximation
  - Monte-Carlo
- Lifting (many BDDs have same structure)
- Learning DTProbLog programs
- Inverse reinforcement learning

Thank You!

Viral Marketing

Decisions

```
? :: marketed(P) :- person(P).
```

Probabilistic Facts

```
0.3 :: buy_trust(_,_).
0.2 :: buy_marketing(_).
```

Background Knowledge

```
buys(X) :-                        buys(X) :-
    trusts(X,Y),                      marketed(X),
    buys(Y),                          buy_marketing(X).
    buy_trust(X,Y).
```

Utility Facts

```
buys(P) => 5 :- person(P).
marketed(P) => -3 :- person(P).
```