A Joint Model for Entity Analysis: Coreference, Typing, and Linking

Greg Durrett and Dan Klein

UC Berkeley

The Entity Stack

Dell reported earnings at a press conference in Austin.

The Entity Stack

ORG EVENT LOC

Dell reported earnings at a press conference in Austin.

The Entity Stack

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NER

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The company had stronger than expected growth.

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Link

Coref

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The Entity Stack

Dell reported earnings …

Link

Coref

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Coref

NER

The Entity Stack

ORG

Dell reported earnings …

Link

Coref

NER

The Entity Stack

PER ORG

Dell reported earnings …

Link

Coref

NER

The Entity Stack

PER ORG

Dell reported earnings …

The company had …

Link

Coref

NER

The Entity Stack

PER ORG

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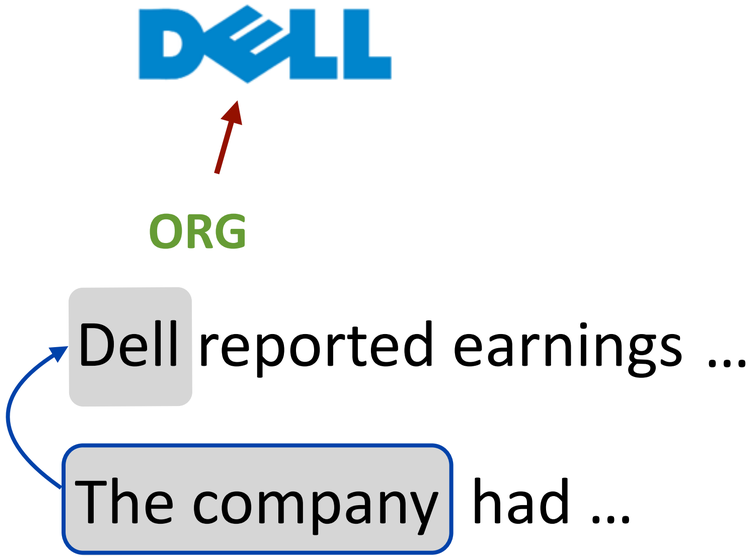
Link

Coref

NER

The Entity Stack

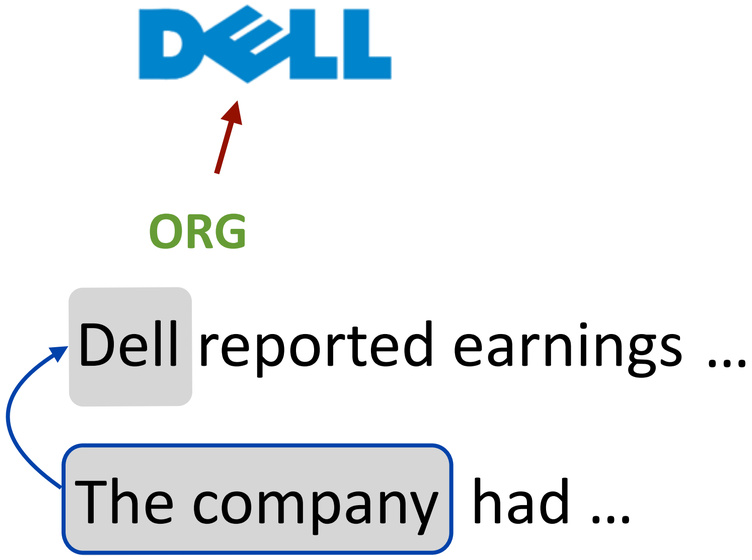


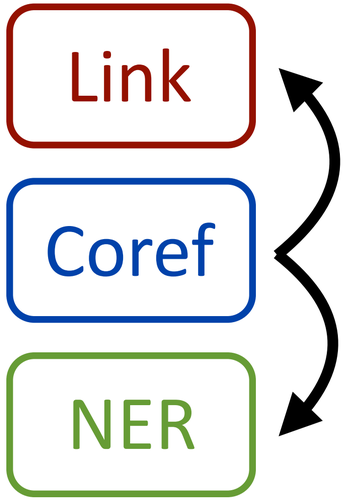
Link

Coref

NER

The Entity Stack

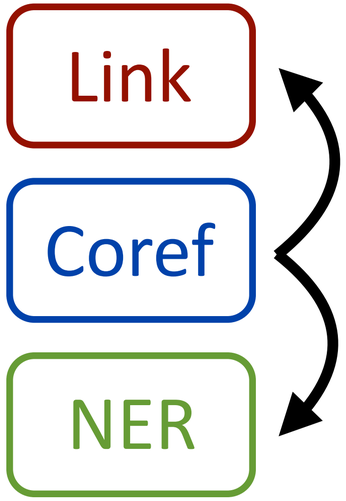




The Entity Stack

Dell reported earnings …

The company had …



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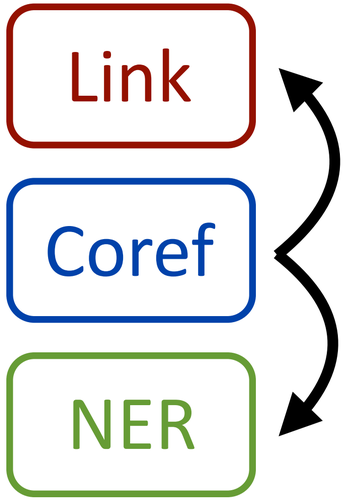

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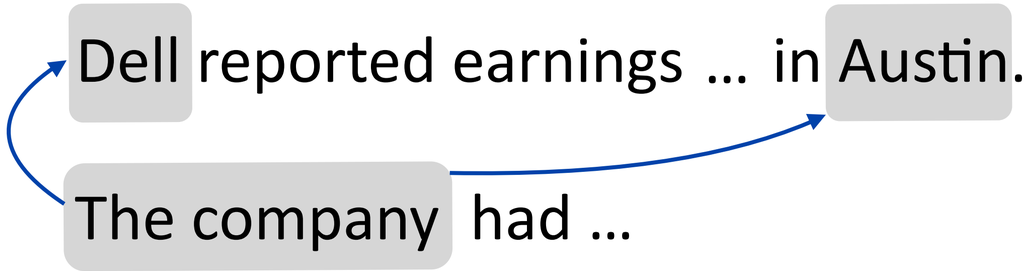

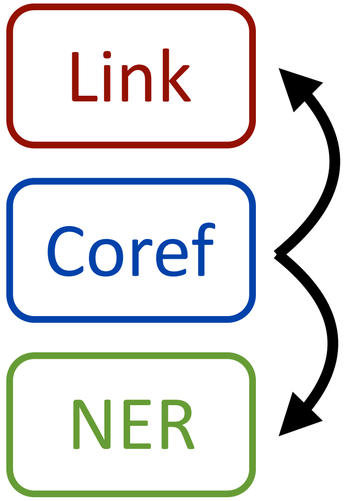

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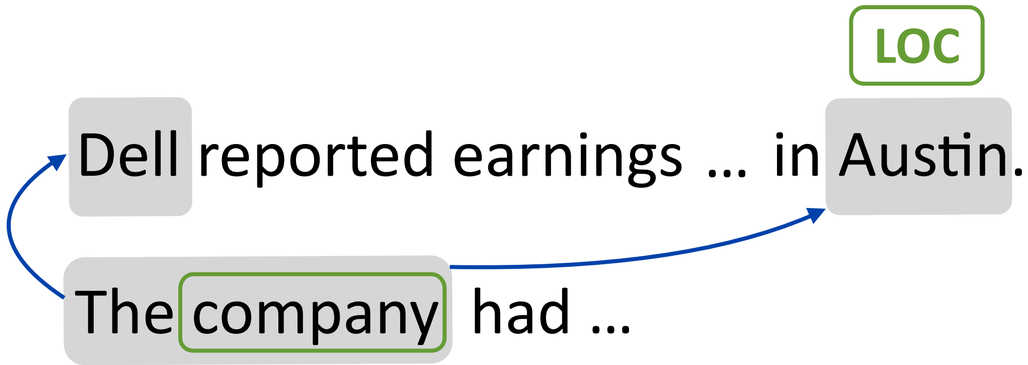

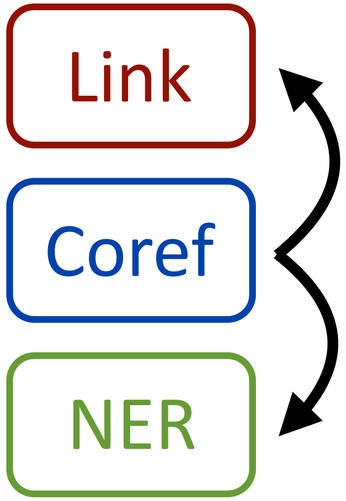

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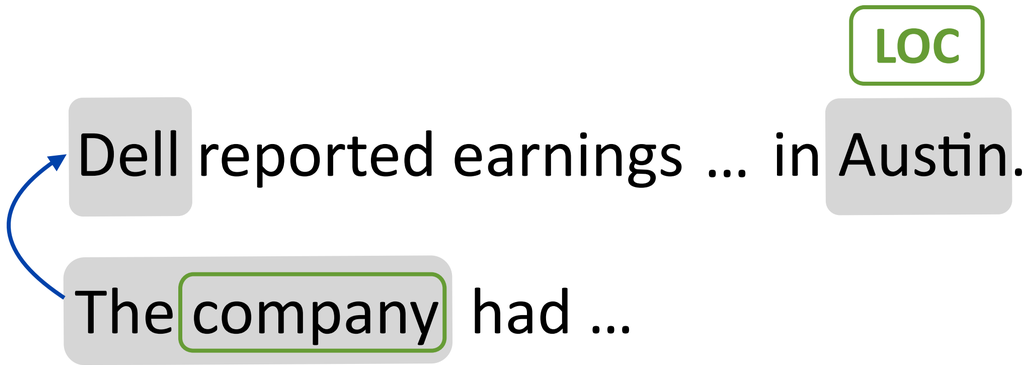

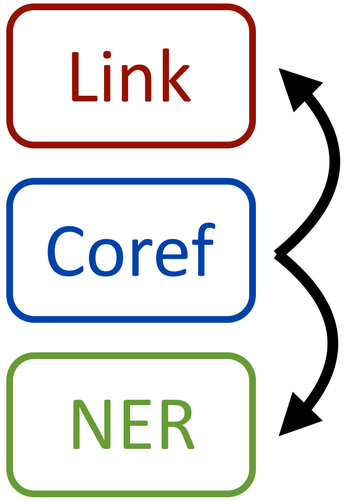

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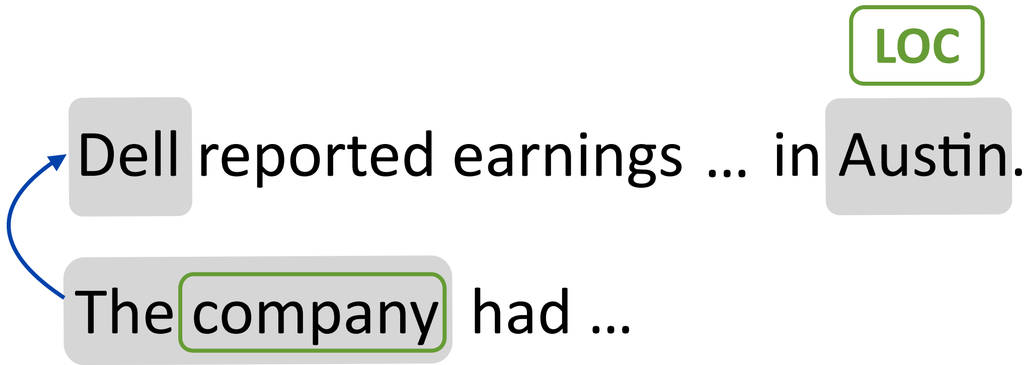
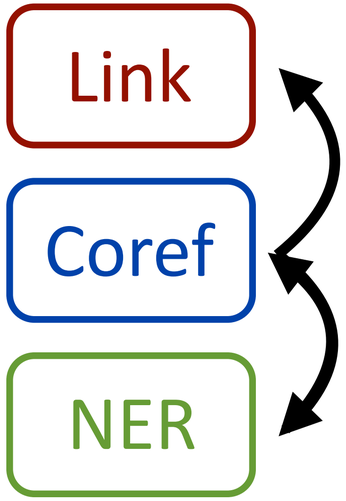
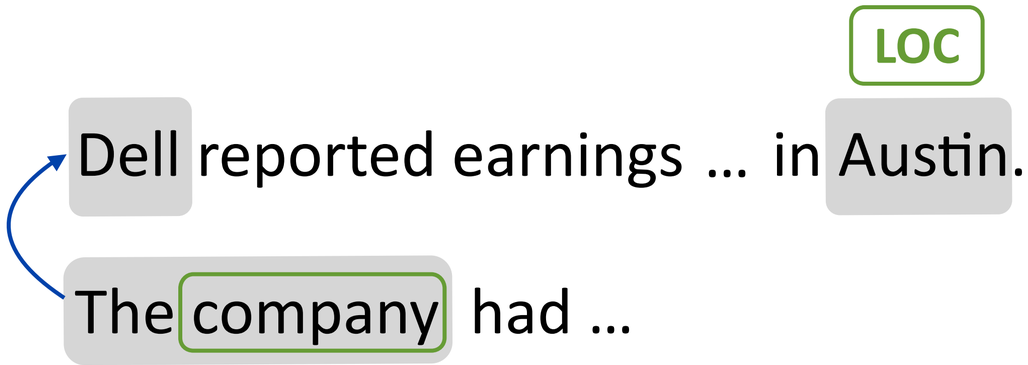
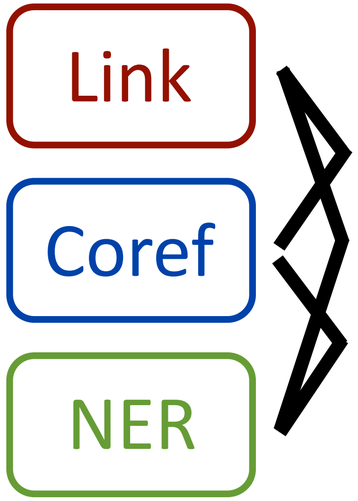




The Entity Stack



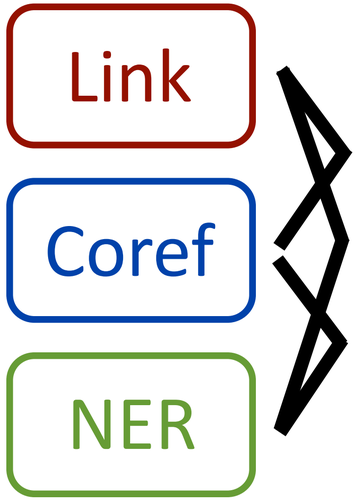


The Entity Stack

LOC

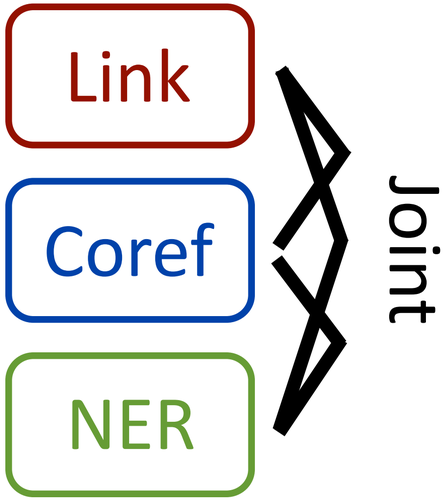
Dell reported earnings … in Austin.

The company had …



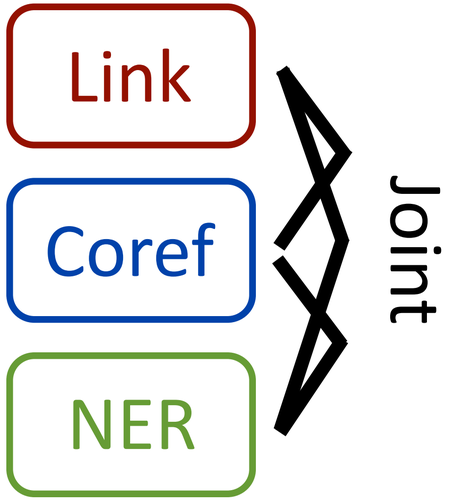
Model and predict the three tasks jointly

Outline



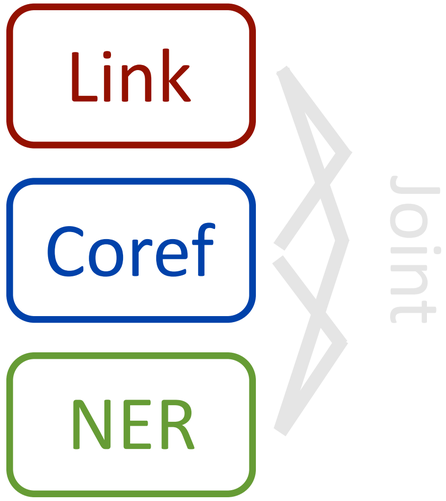
Outline

- Model



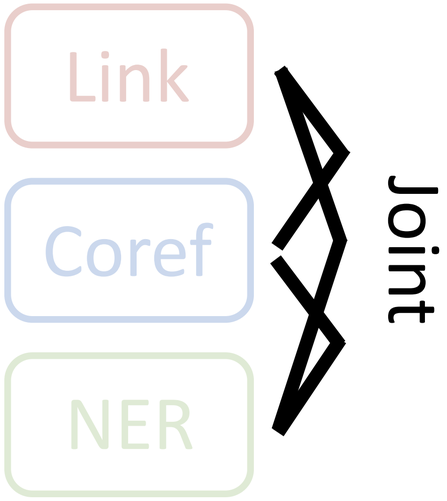
Outline

- Model
  - Independent models (unary, per-task factors)



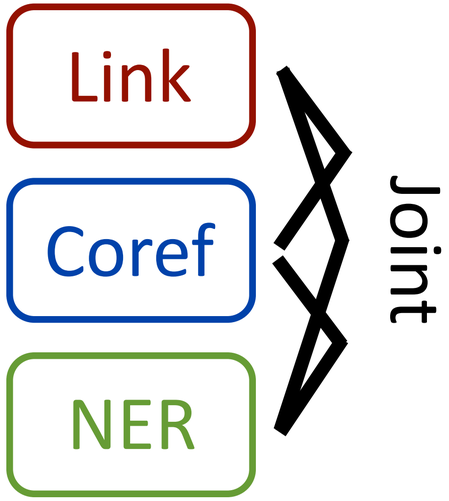
Outline

- Model
  - Independent models (unary, per-task factors)
  - Joint coupling (higher-arity, cross-task factors)



Outline

- Model
  - Independent models (unary, per-task factors)
  - Joint coupling (higher-arity, cross-task factors)
- Experiments



Model

Dell

Austin

The company

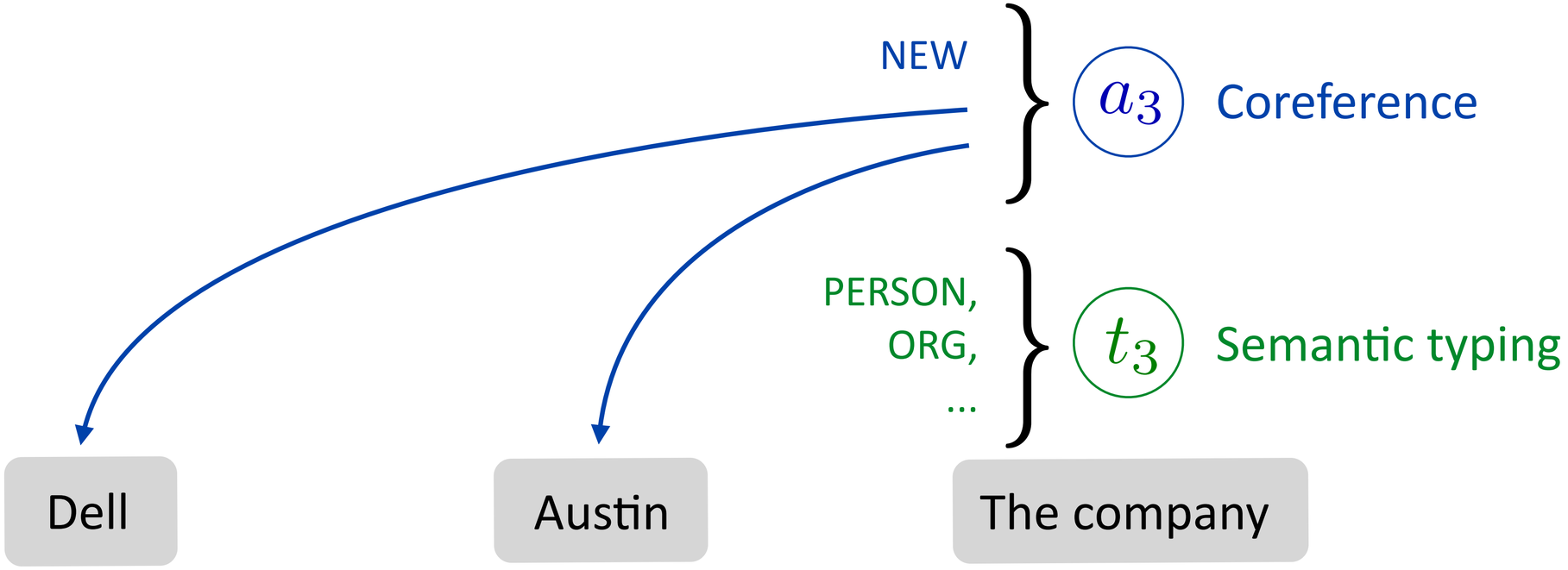
Model

Dell

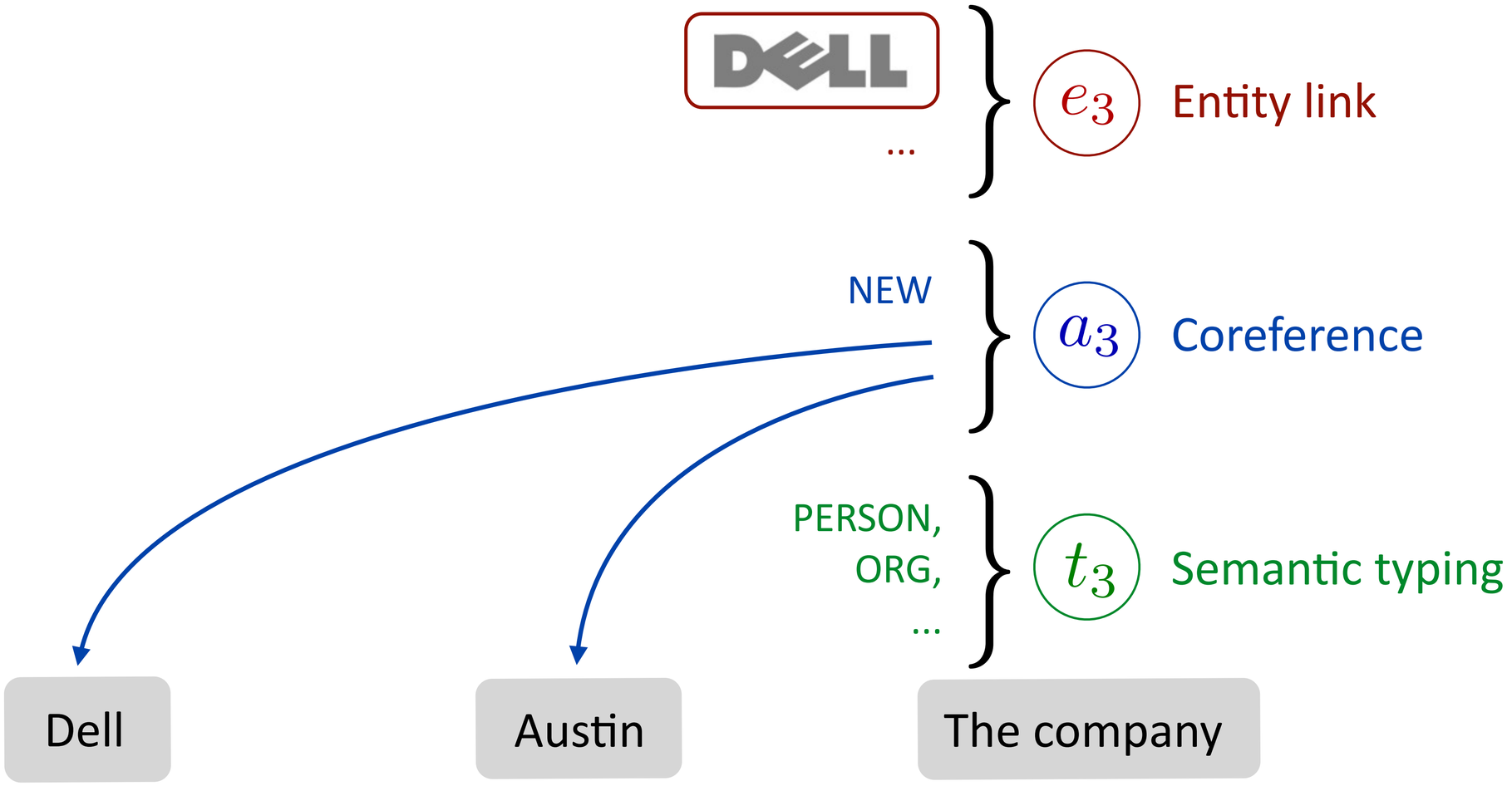
Austin

The company

Model


NEW
a_3
Coreference
PERSON,
ORG,
...
t_3
Semantic typing
Dell
Austin
The company

Model


...
e_3
Entity link
NEW
a_3
Coreference
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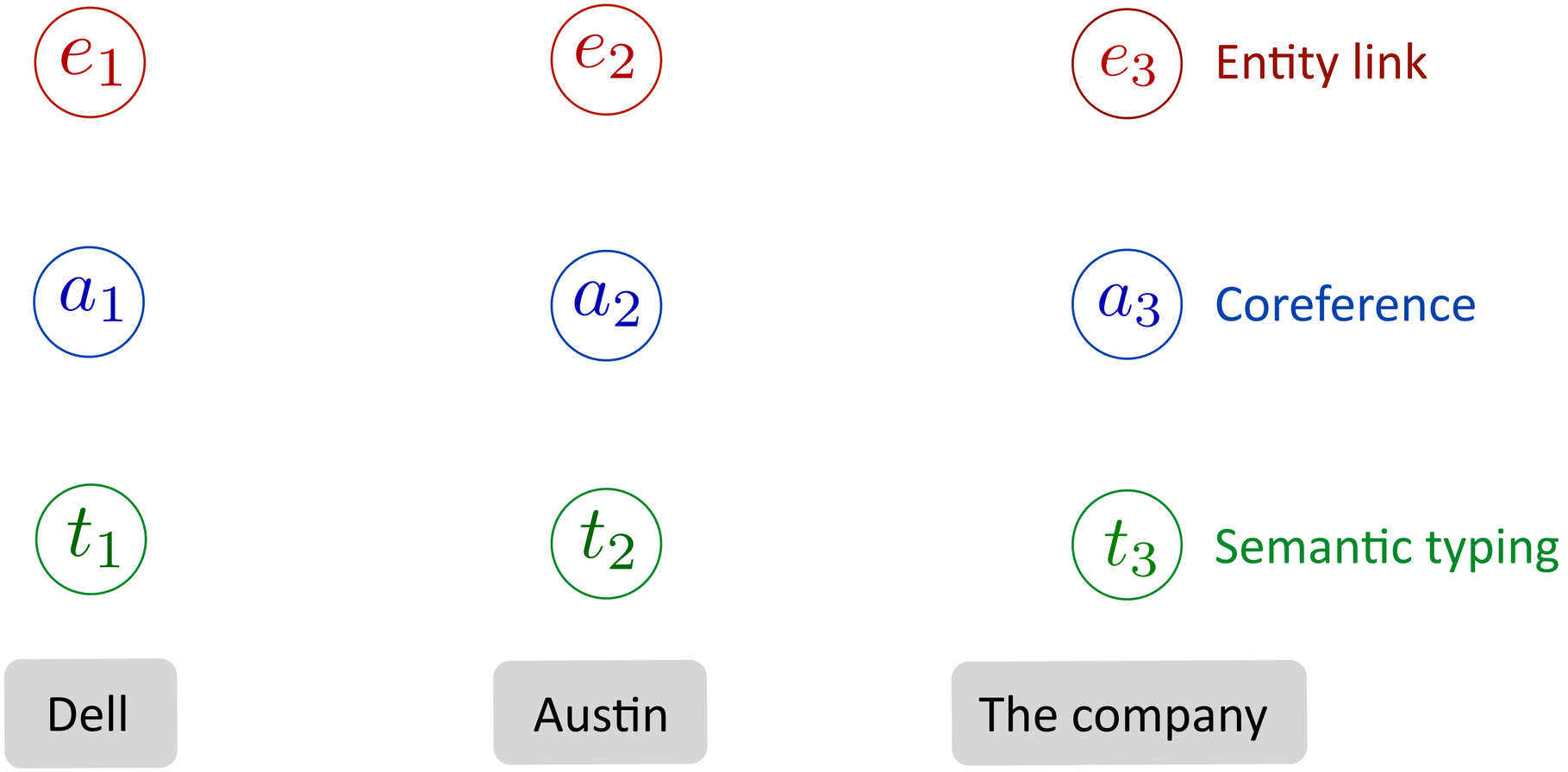
Model


e_1
e_2
e_3
Entity link
a_1
a_2
a_3
Coreference
t_1
t_2
t_3
Semantic typing
Dell
Austin
The company

Model

e_1

a_1

t_1

Dell

Model

$$\mathbf{p}(\mathbf{t}, \mathbf{a}, \mathbf{e} | \mathbf{x}) \propto \exp\left(\mathbf{w}^\top \mathbf{f}(\mathbf{x}, \mathbf{t}, \mathbf{a}, \mathbf{e})\right)$$

e_1

a_1

t_1

Dell

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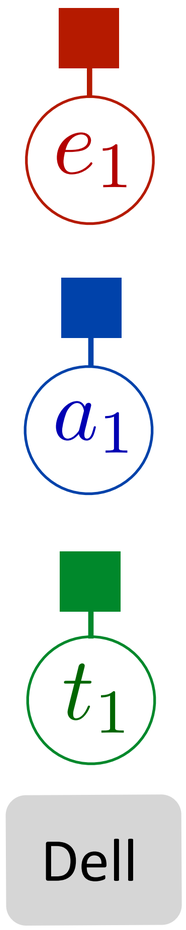

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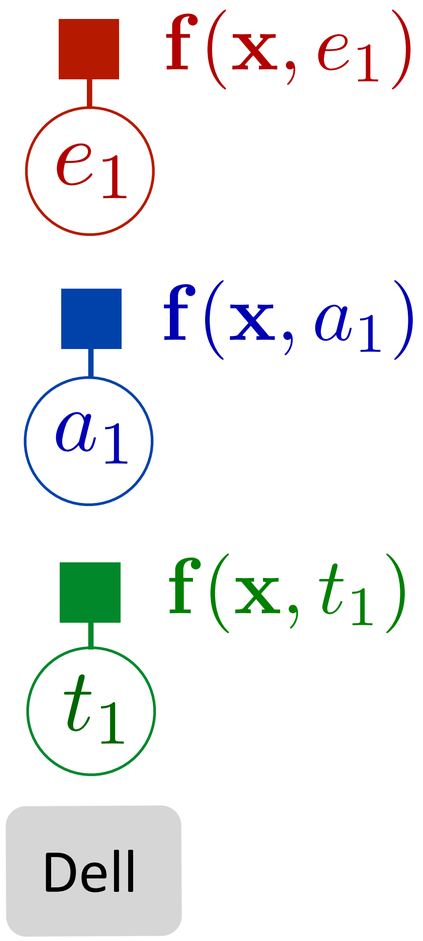

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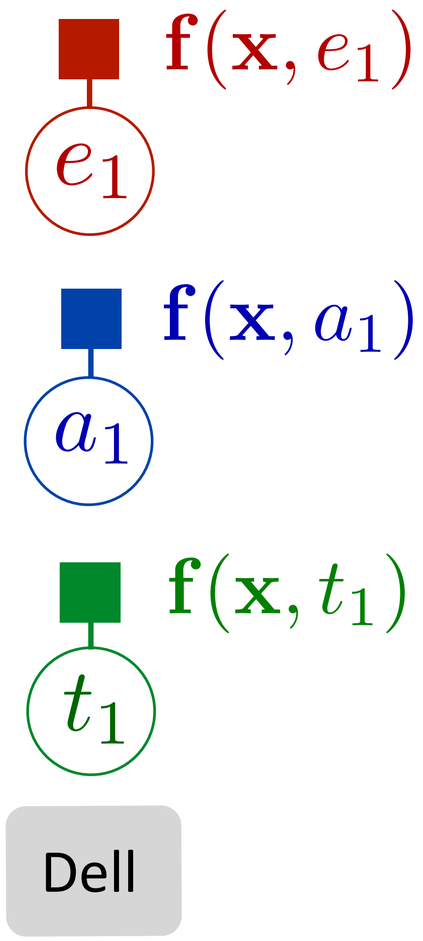


Semantic Typing (NER)

t_1 { **PERSON**
ORG
…

<s> Dell reported earnings at a press conference …

Semantic Typing (NER)

t_1 { **PERSON**
ORG
…

<s> Dell reported earnings at a press conference …

Semantic Typing (NER)

t_1 { **PERSON**
ORG
…

POS tags

<s>	Dell	reported	earnings	at a press conference …
	NNP	VBZ	NNP	

Semantic Typing (NER)

t_1 { **PERSON**, **ORG**, **…** }

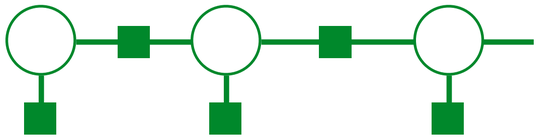
	<s> Dell	reported	earnings	at a press conference …
POS tags	NNP	VBZ	NNP	
Word shapes	X_	_ed	_s	

Semantic Typing (NER)

t_1 { **PERSON**, **ORG**, **…** }

	<s> Dell	reported	earnings	at a press conference …
POS tags	NNP	VBZ	NNP	
Word shapes	X_	_ed	_s	
Brown clusters	0001	1010	0011	

Semantic Typing (NER)



	<s>	Dell	reported	earnings
POS tags		NNP	VBZ	NNP
Word shapes		X_	_ed	_s
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at a press conference …

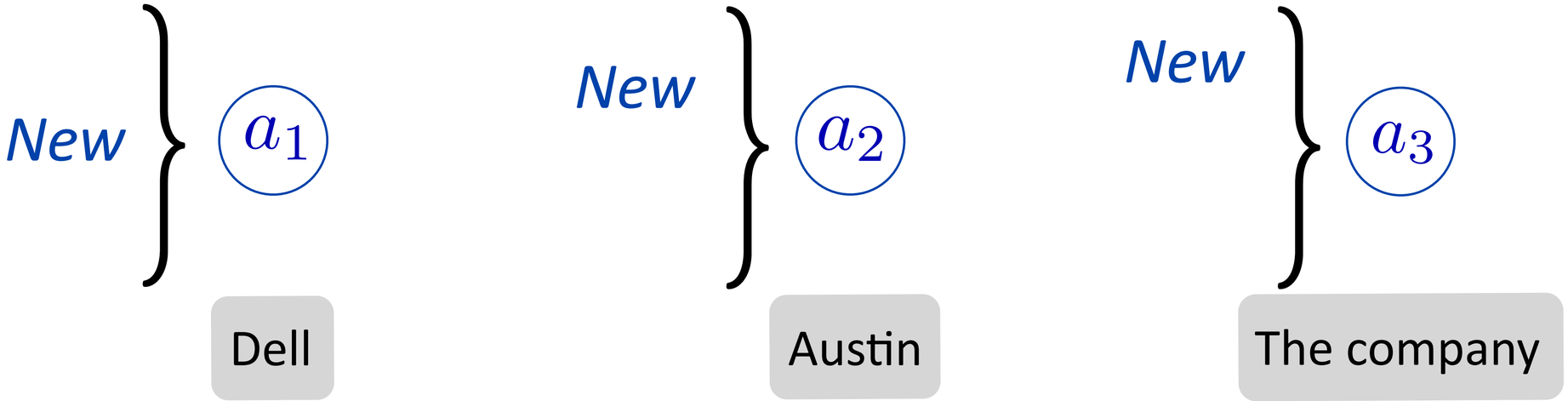
Coreference Resolution

a_1 a_2 a_3

Dell Austin The company

[Durrett and Klein (2013)]

Coreference Resolution



[Durrett and Klein (2013)]

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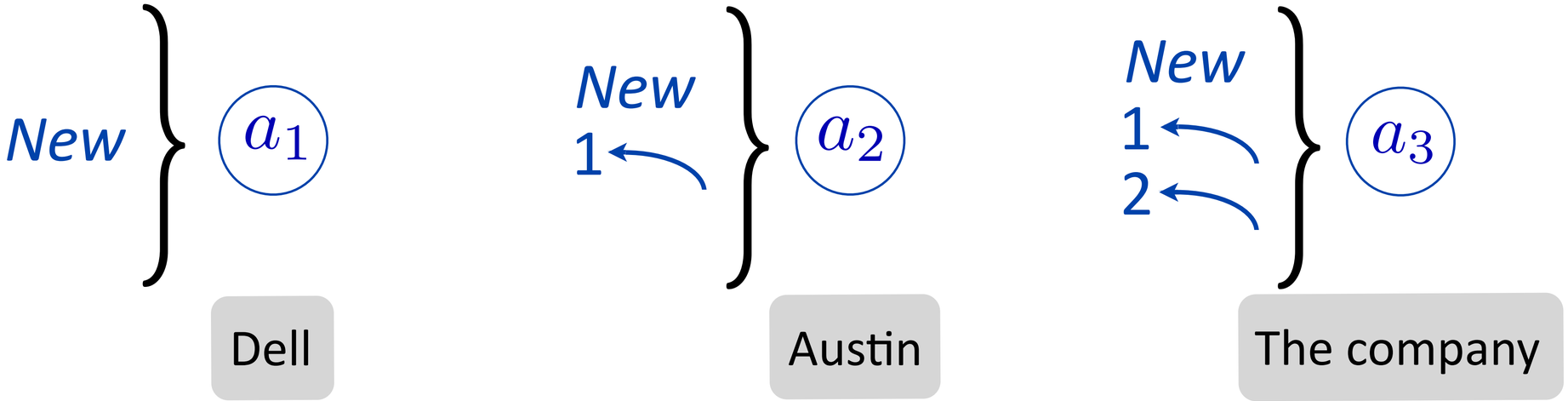

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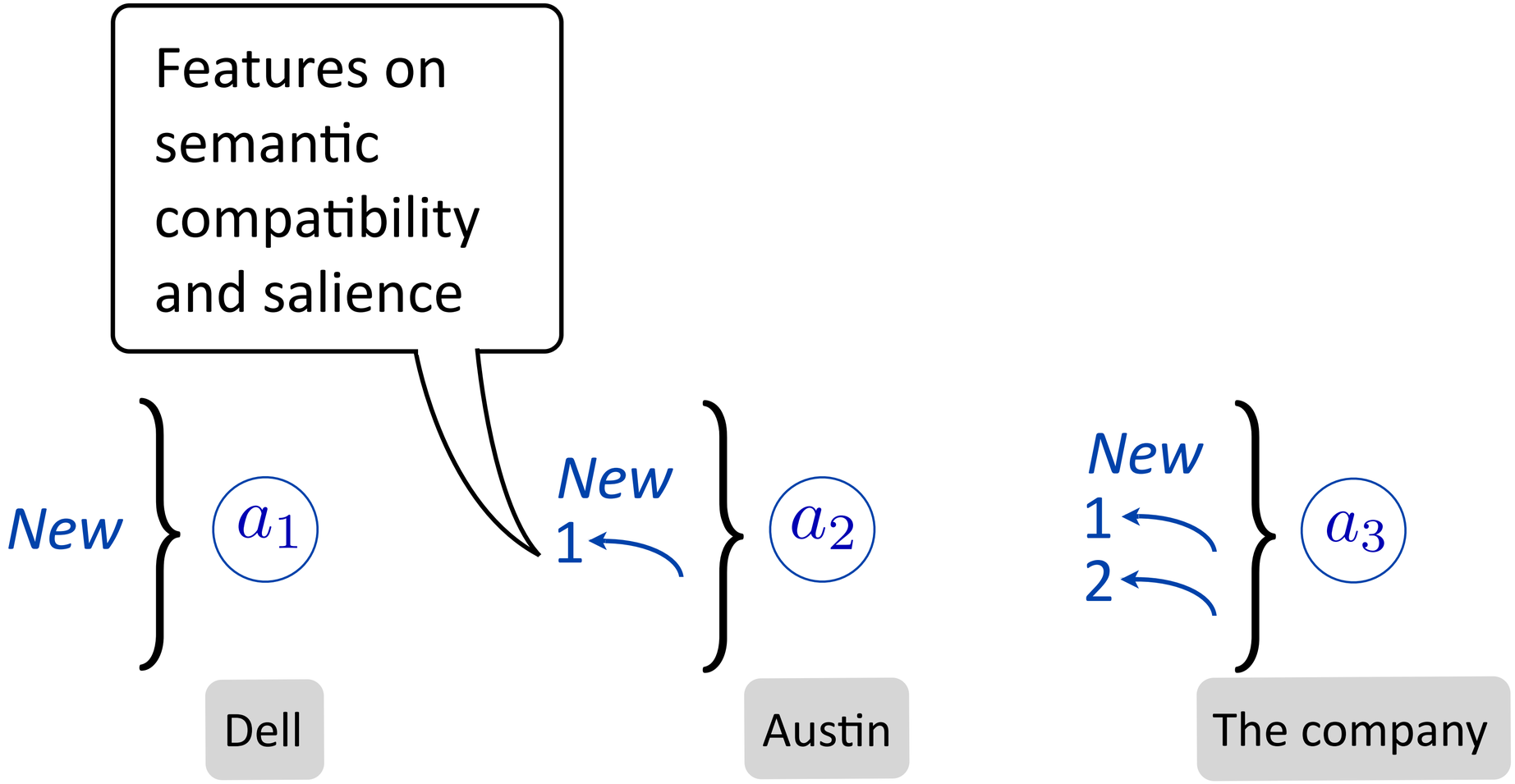
Coreference Resolution



[Durrett and Klein (2013)]

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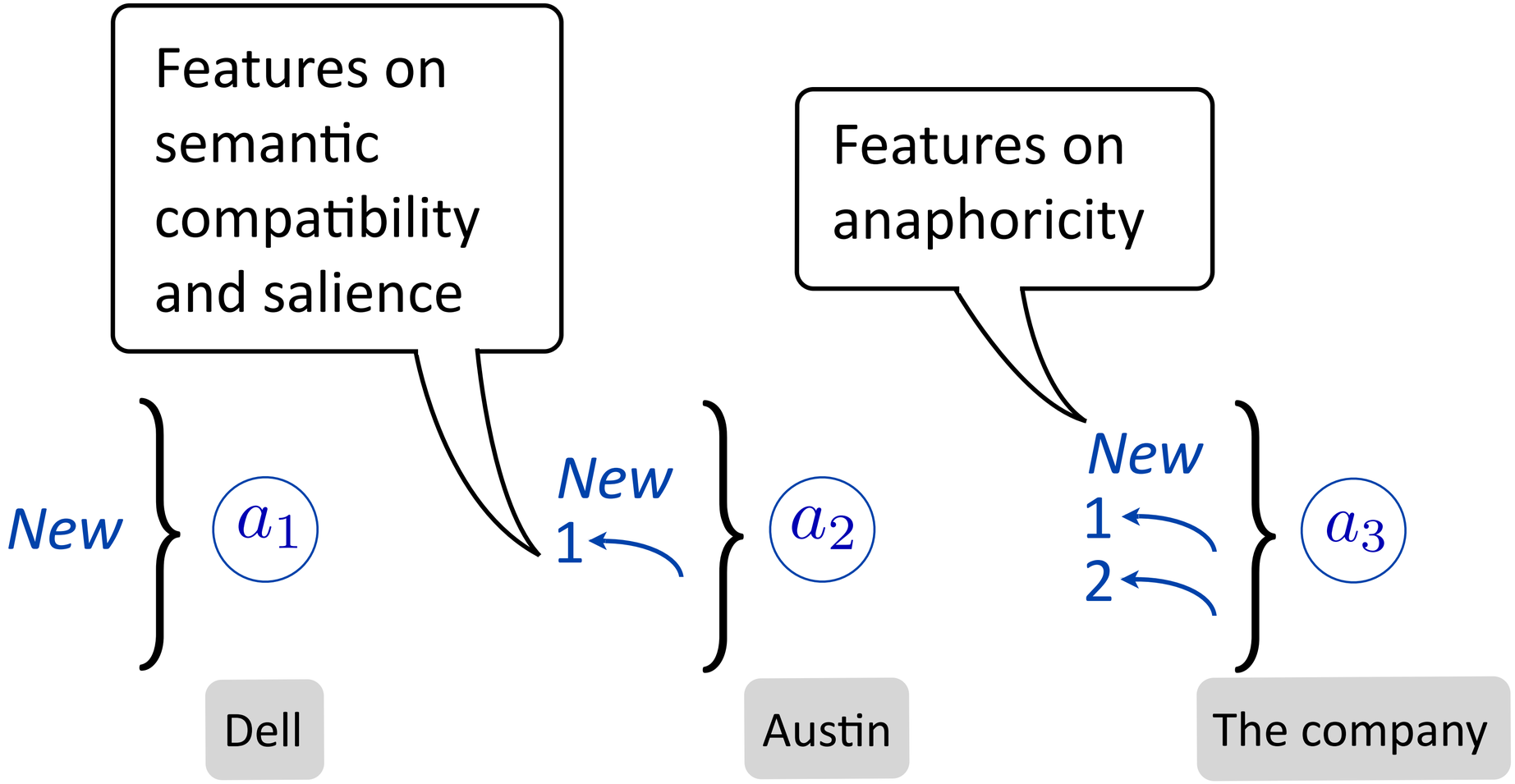

[Durrett and Klein (2013)]

Entity Linking

e_1

Dell

Entity Linking

e_1

Michael Dell

Dell, Inc.

Dell Comics

...

Dell

Entity Linking

WIKIPEDIA
The Free Encyclopedia

>4 million articles

e_1

Michael Dell
Dell, Inc.
Dell Comics
...

Dell

Aardvark
Aaron Burr
...
Zebra
Zimbabwe

Hyperlink Anchor Text

[Cucerzan 2007; Milne and Witten, 2008; Ratinov et al., 2011]

Hyperlink Anchor Text

Dell

[Cucerzan 2007; Milne and Witten, 2008; Ratinov et al., 2011]

Hyperlink Anchor Text

Dell

Round Rock, Texas

Round Rock is perhaps best known as the international headquarters of Dell, which employs ...

`Dell, Inc.`

[Cucerzan 2007; Milne and Witten, 2008; Ratinov et al., 2011]

Hyperlink Anchor Text

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↓

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With partners Dell and Simon & Schuster, the company ...

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...

[Cucerzan 2007; Milne and Witten, 2008; Ratinov et al., 2011]

Query Selection

Query Selection

CEO Michael Dell

Query Selection

CEO Michael Dell

CEO Michael Dell [none]

Query Selection

CEO Michael Dell

CEO Michael Dell [none]

Dell

Query Selection

CEO Michael Dell

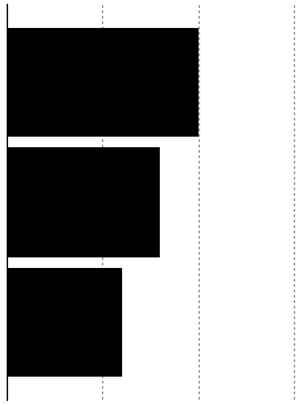
CEO Michael Dell [none]

Michael Dell Michael Dell

Dell Dell, Inc.

Michael Dell

Dell Comics



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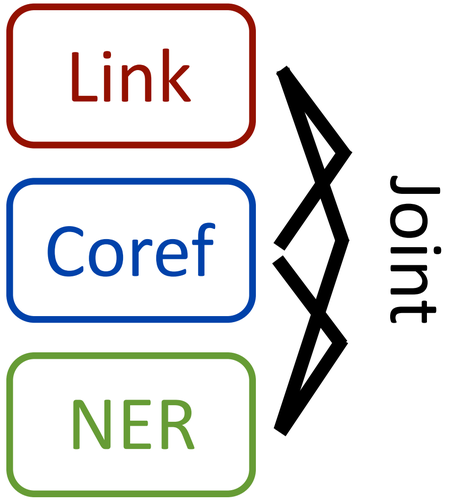

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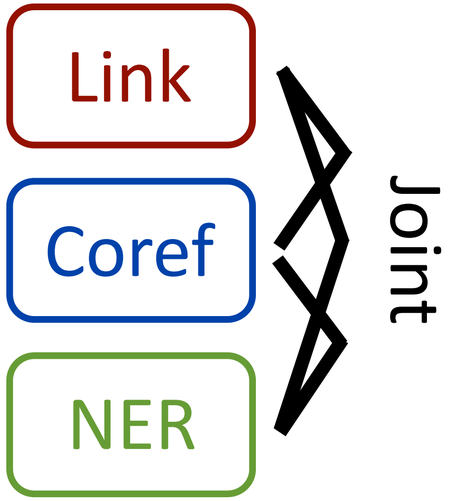
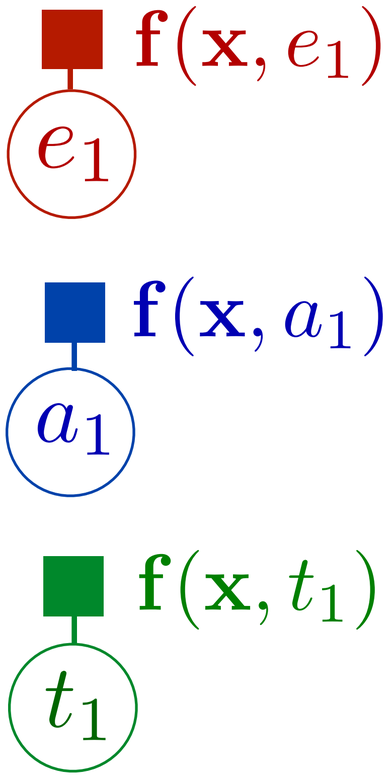


Model

$$\mathbf{p}(\mathbf{t}, \mathbf{a}, \mathbf{e} | \mathbf{x}) \propto \exp\left(\mathbf{w}^\top \mathbf{f}(\mathbf{x}, \mathbf{t}, \mathbf{a}, \mathbf{e})\right)$$

$$\mathbf{f}_{\text{indep}}(\mathbf{x}, \mathbf{t}, \mathbf{a}, \mathbf{e}) = \sum_{i=1}^{n} \left[\mathbf{f}(\mathbf{x}, t_i) + \mathbf{f}(\mathbf{x}, a_i) + \mathbf{f}(\mathbf{x}, e_i)\right]$$



Dell

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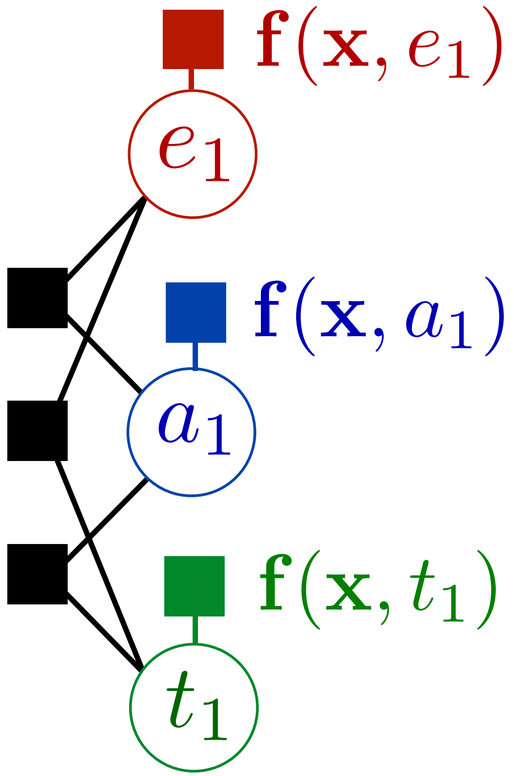

Dell

Model

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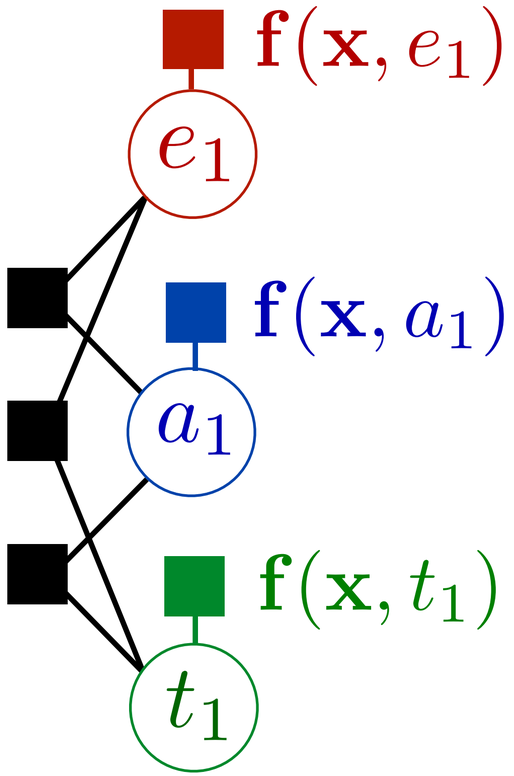
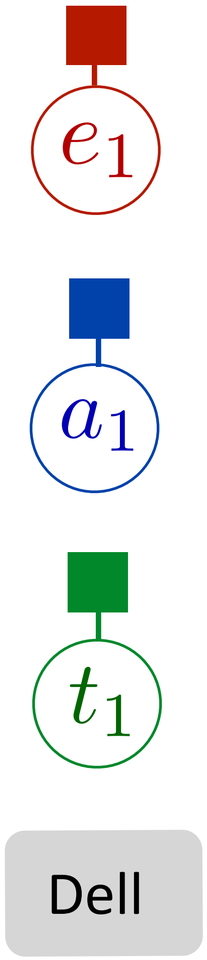
$$\mathbf{f}_{\text{joint}}(\mathbf{x}, \mathbf{t}, \mathbf{a}, \mathbf{e}) = \mathbf{f}_{\text{indep}}(\mathbf{x}, \mathbf{t}, \mathbf{a}, \mathbf{e}) + \sum \text{joint factors}$$

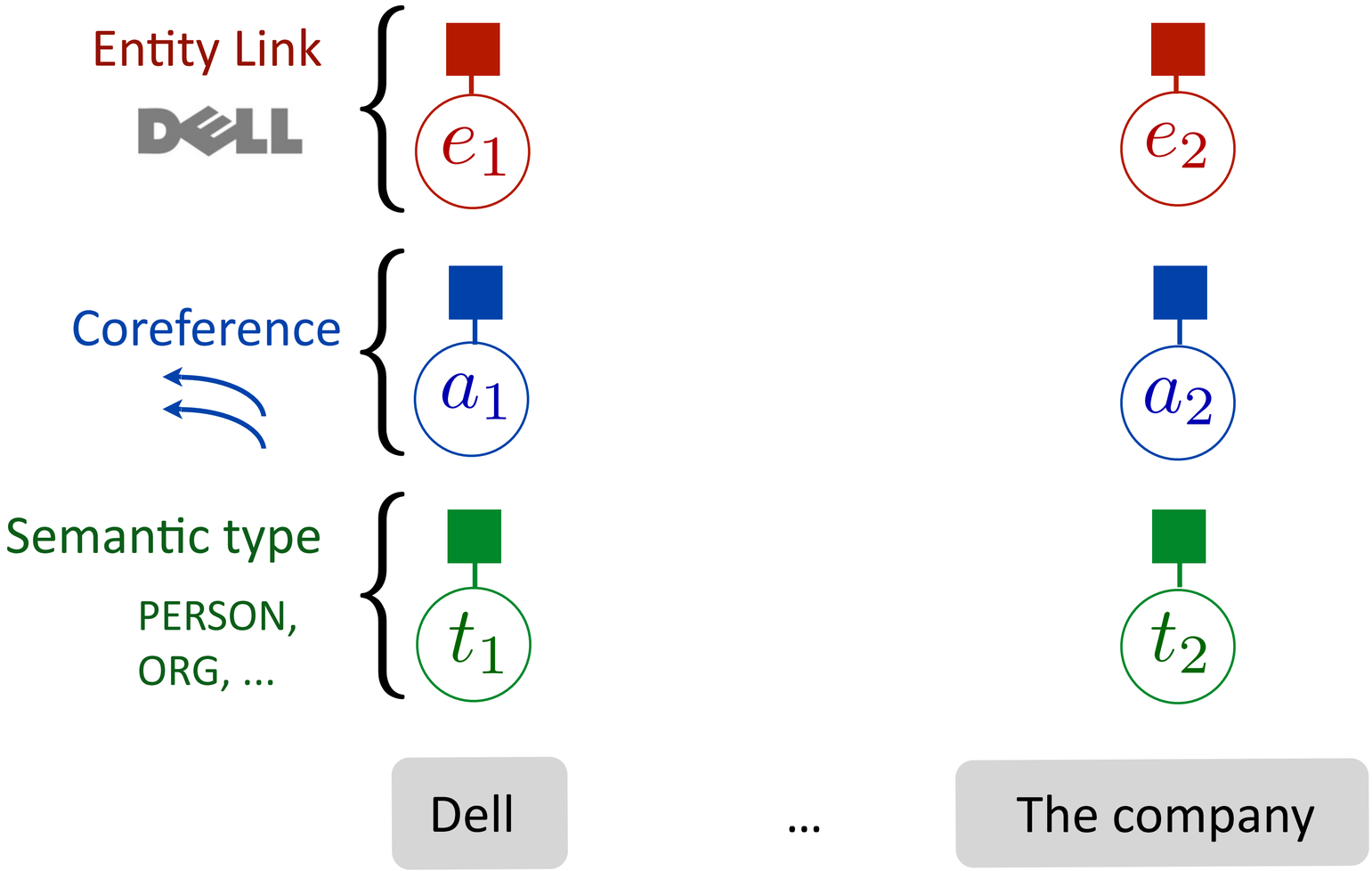


Dell

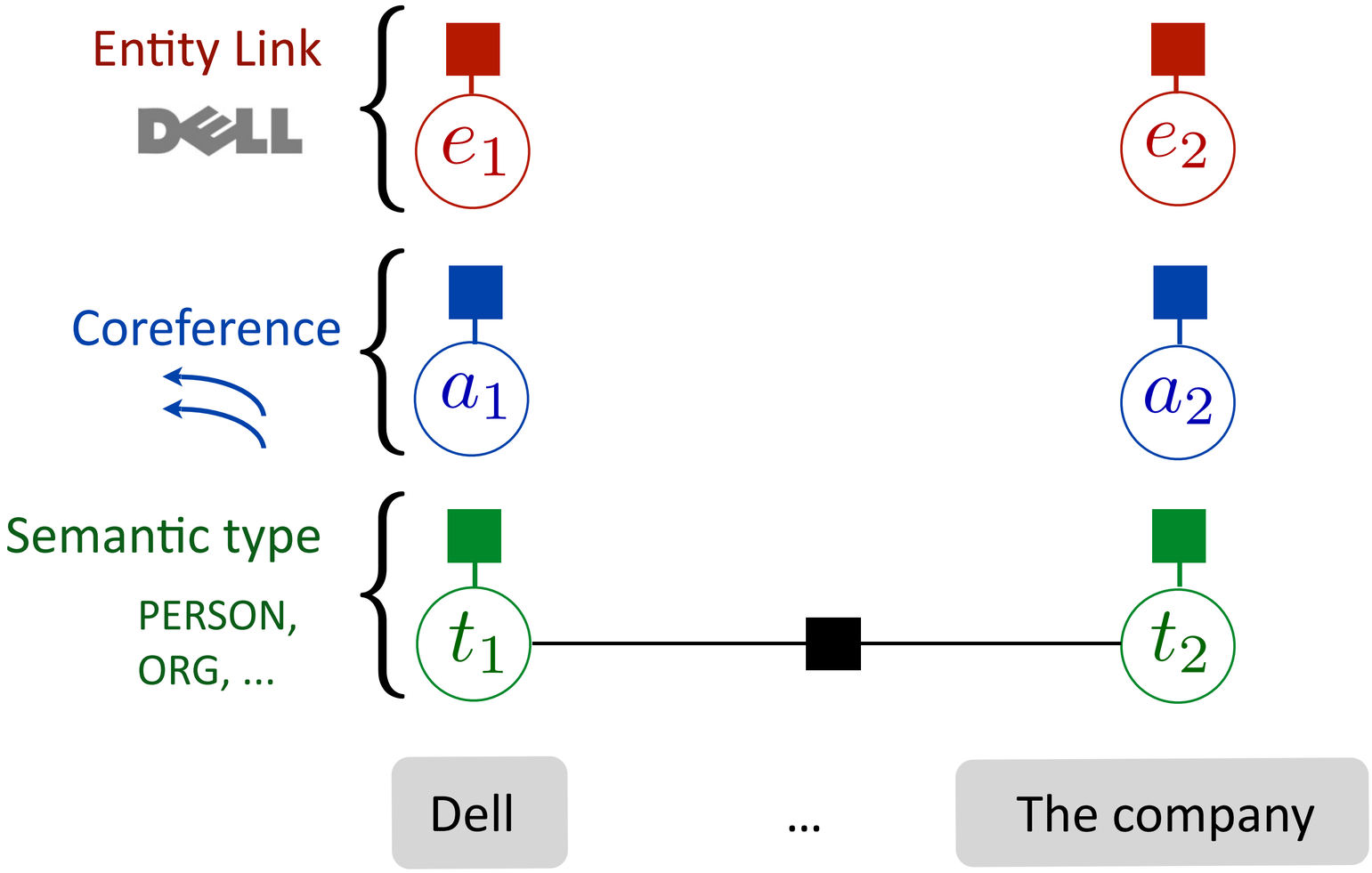
Model



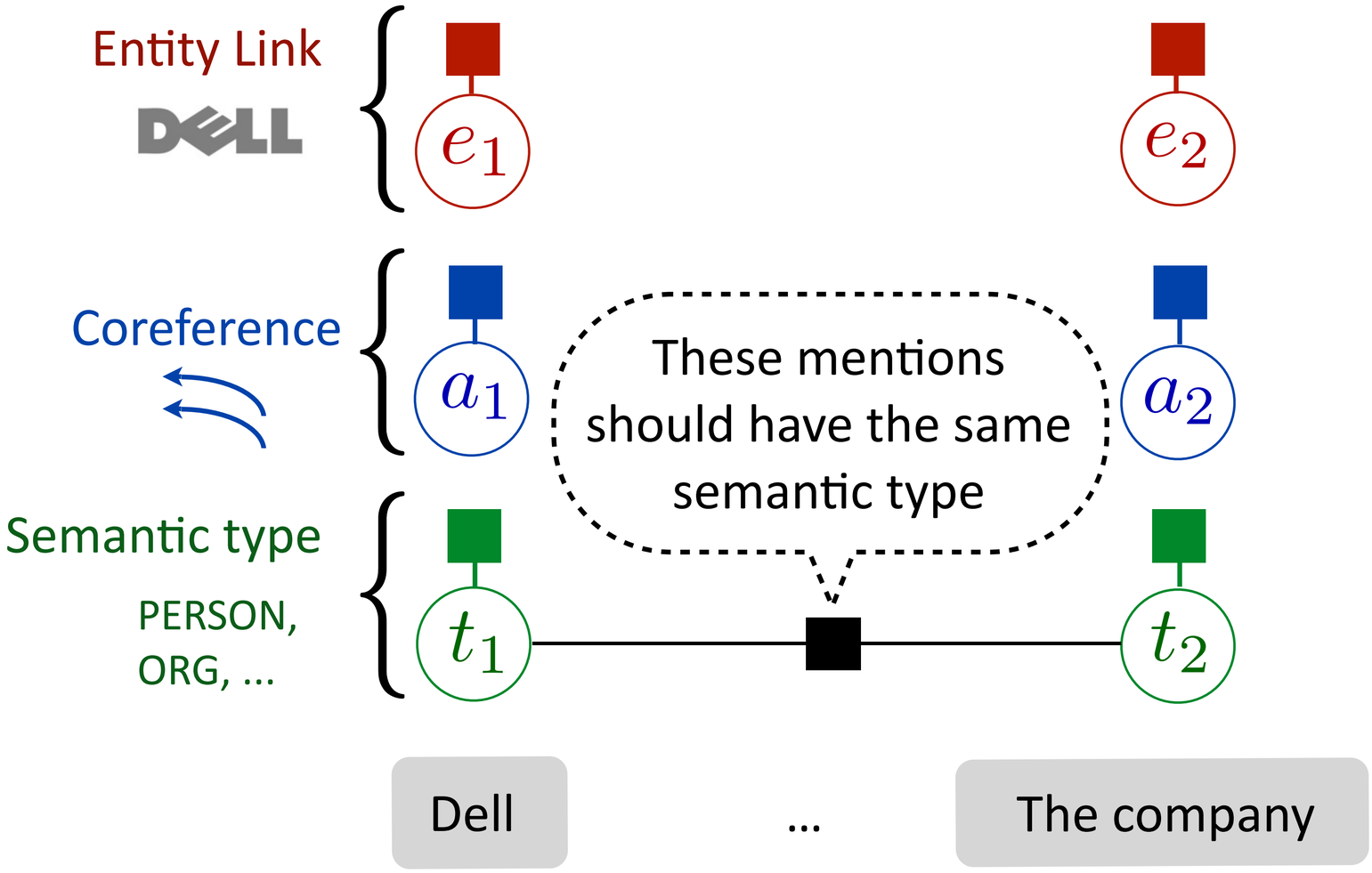
Coreference — Typing



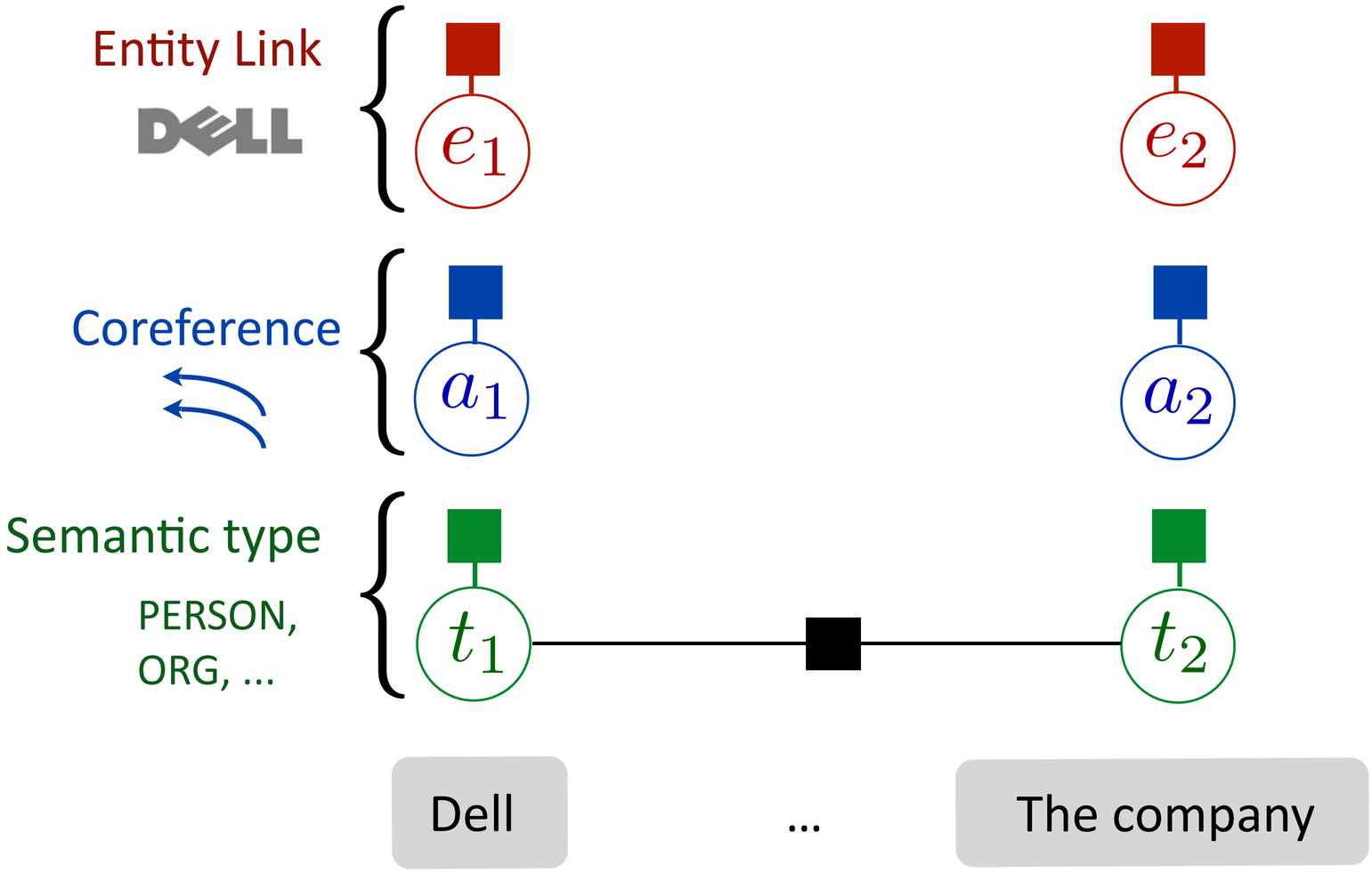
Coreference — Typing



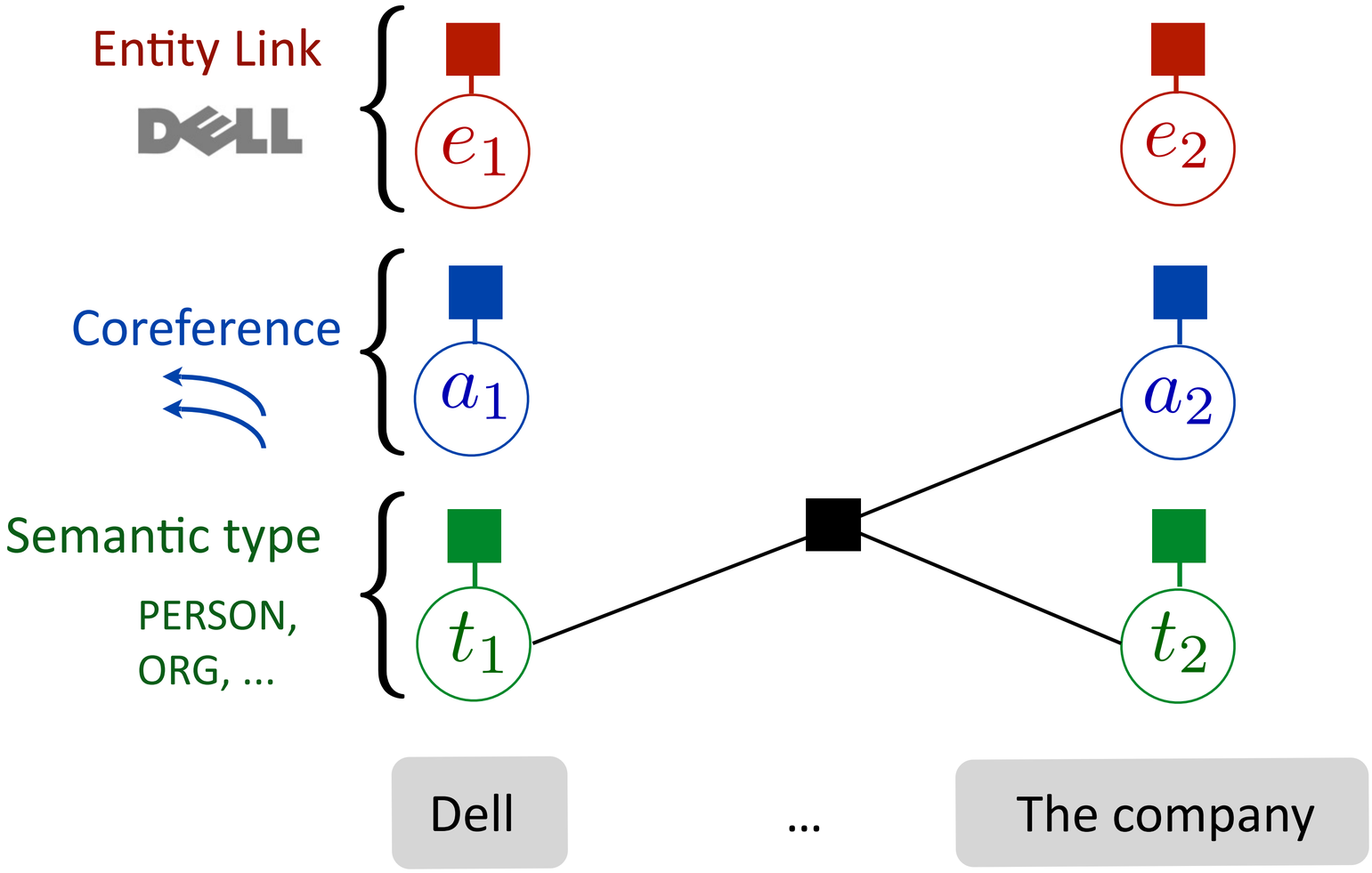
Coreference — Typing



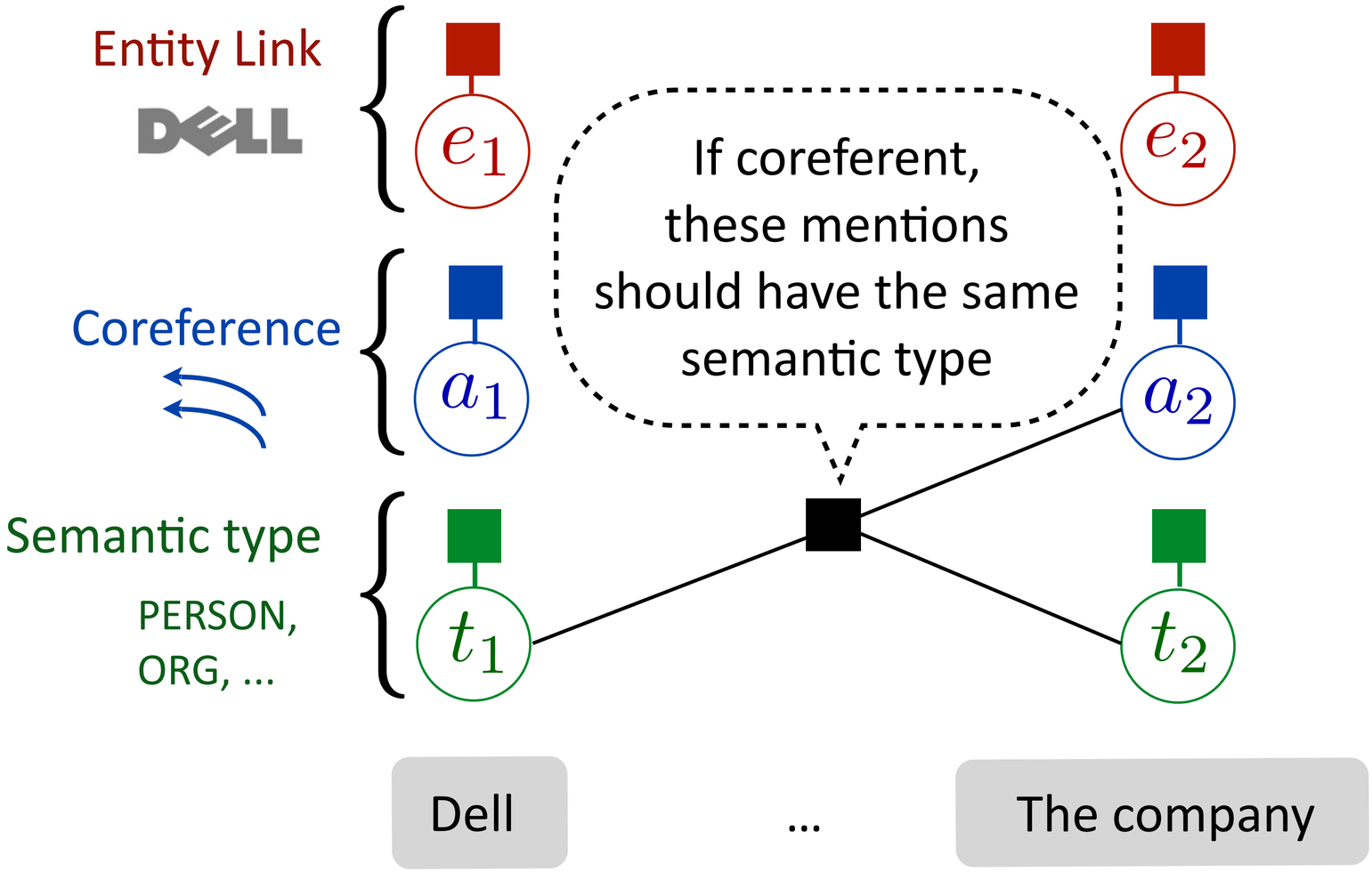
Coreference — Typing



Coreference — Typing



Coreference — Typing



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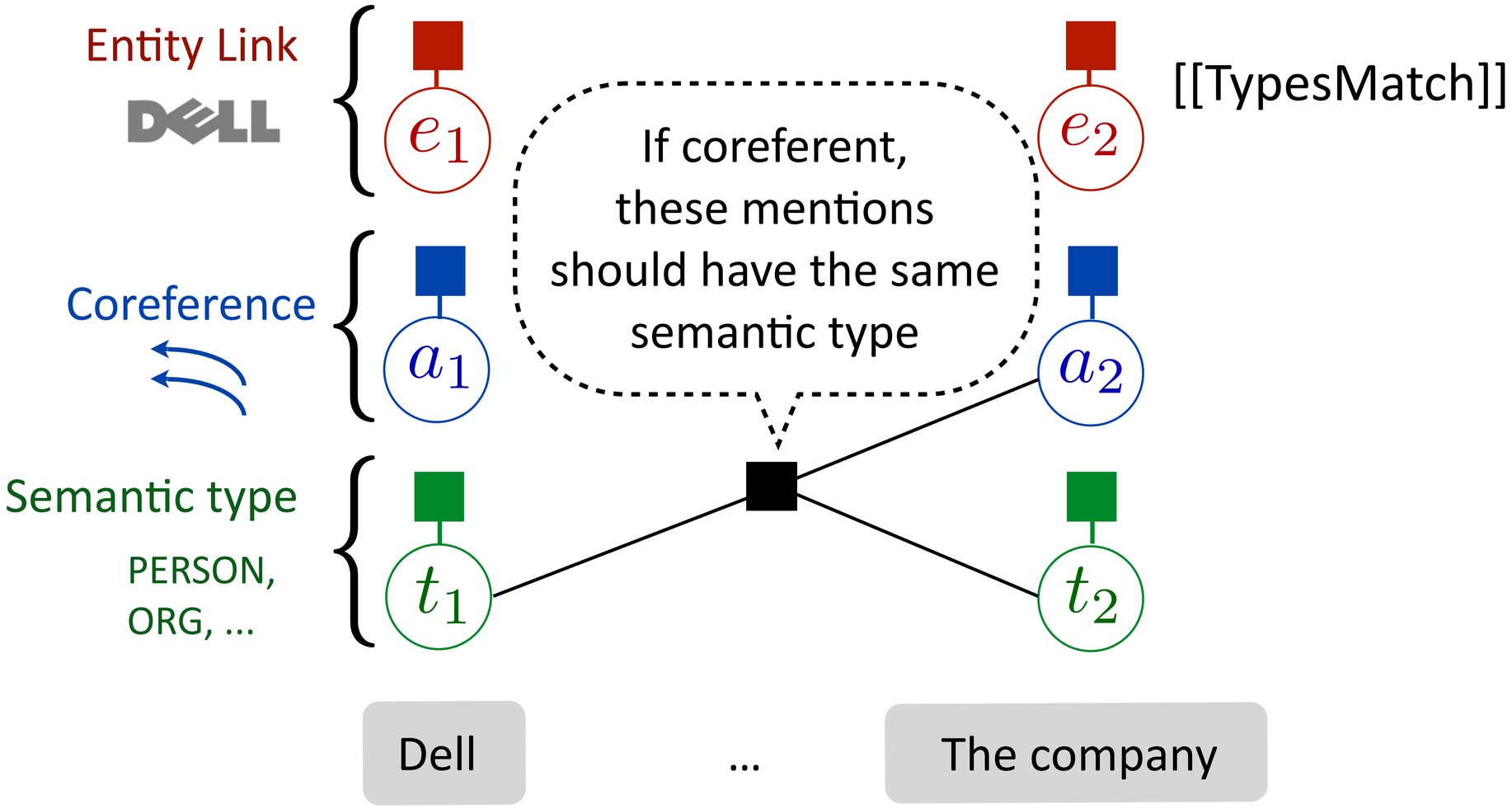

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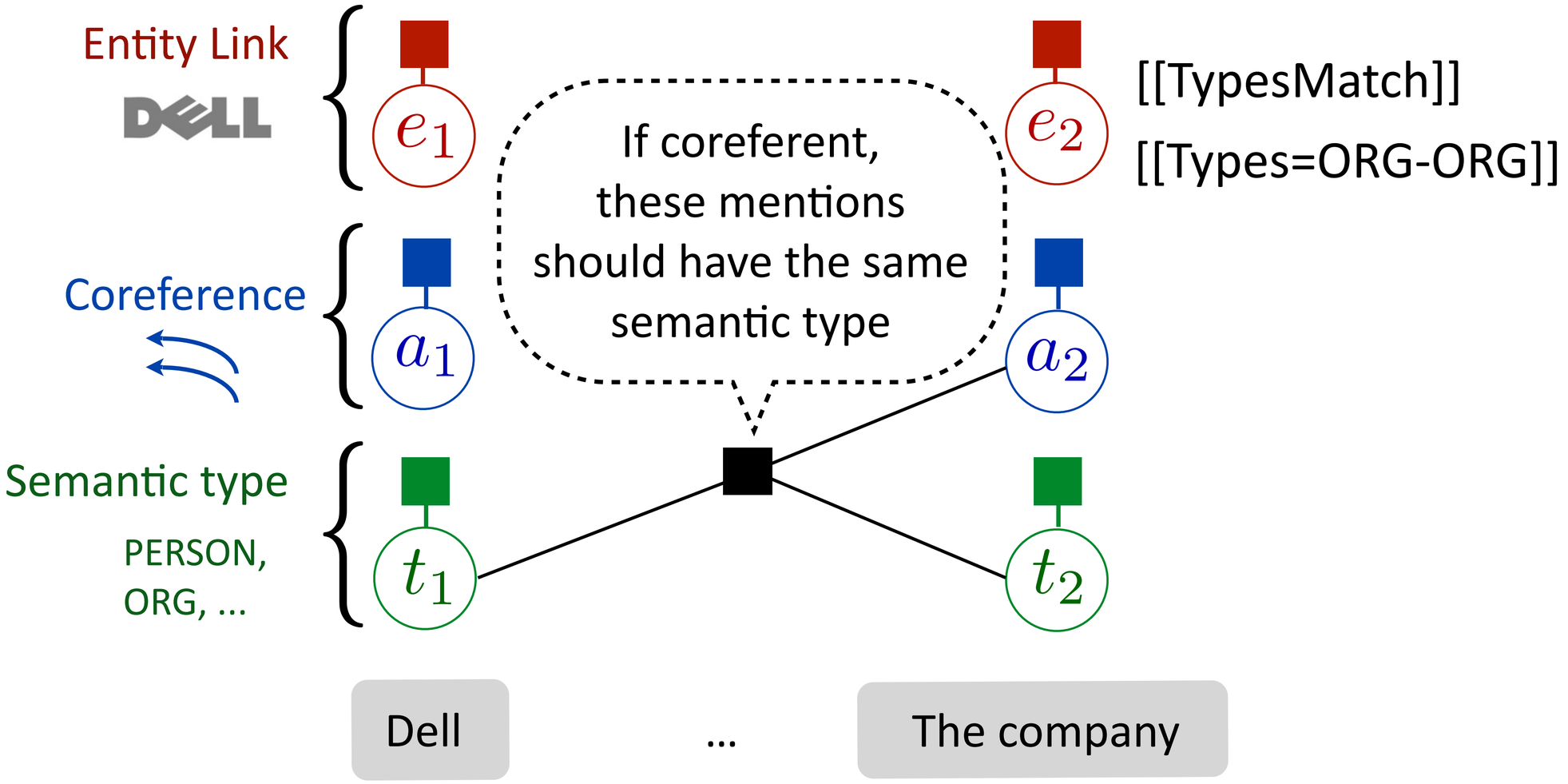
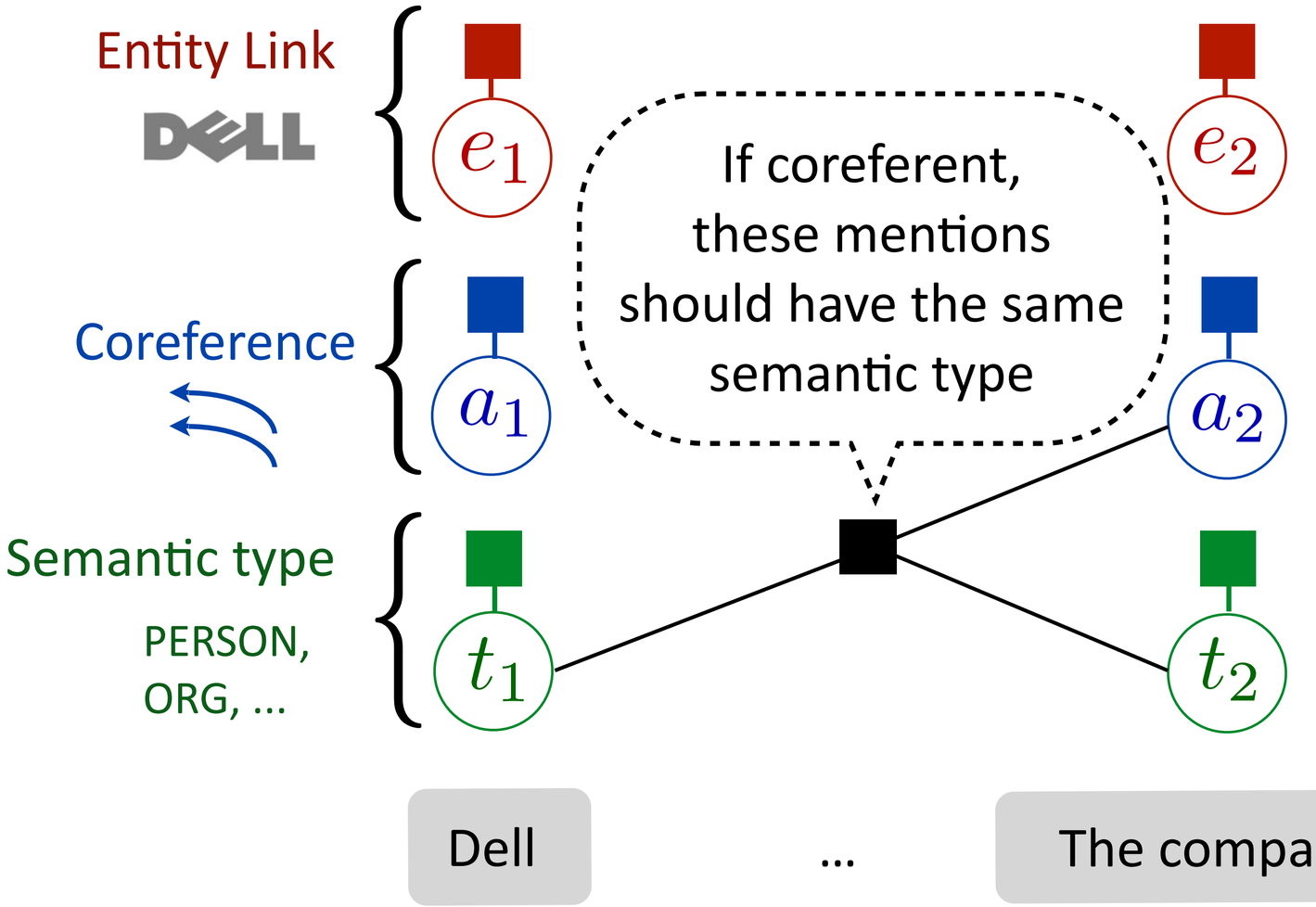


Coreference — Typing



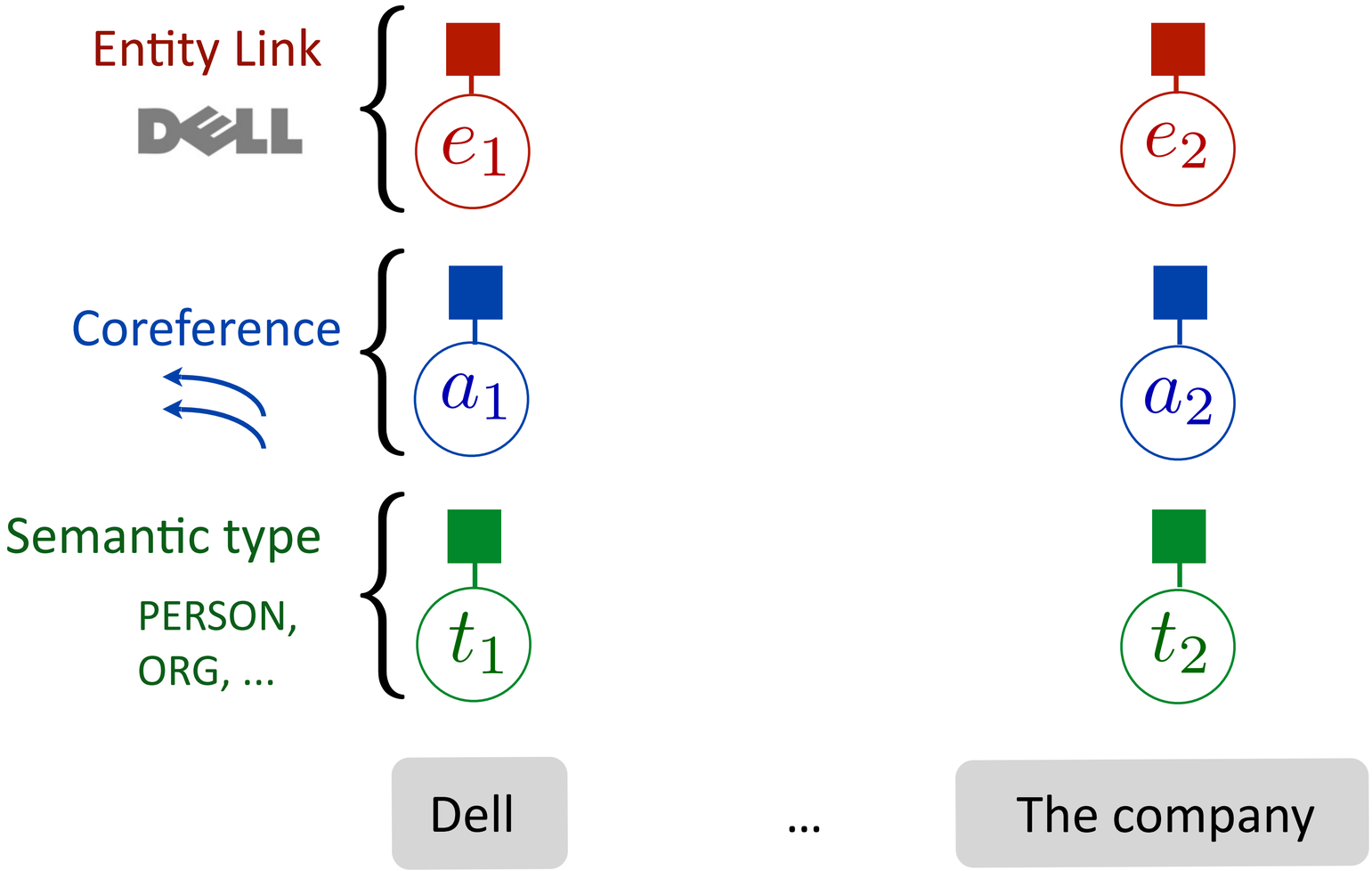
[[TypesMatch]]

[[Types=ORG-ORG]]

[[Curr=*company* PrevType=*ORG*]]

...

Coreference — Linking



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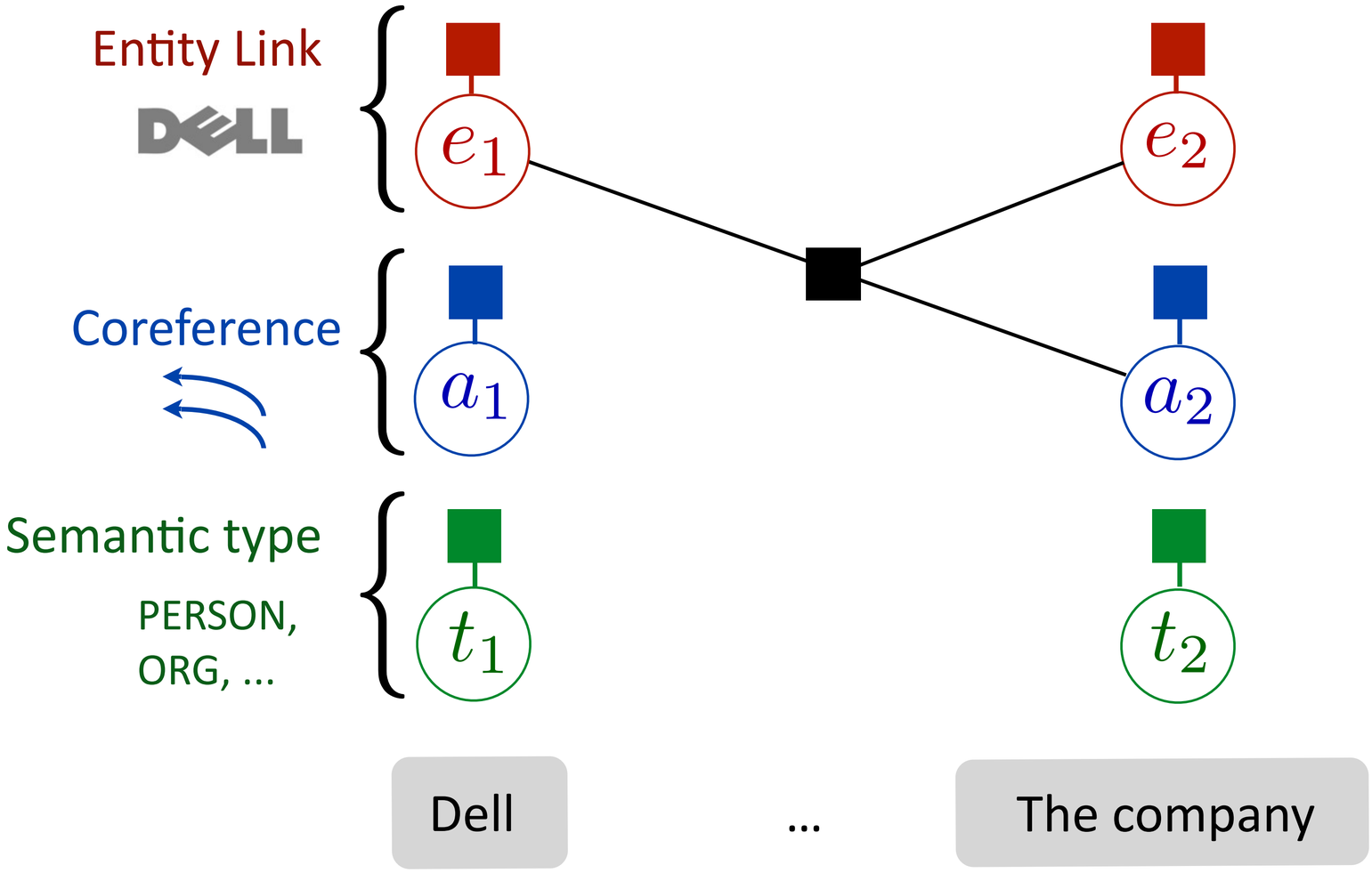
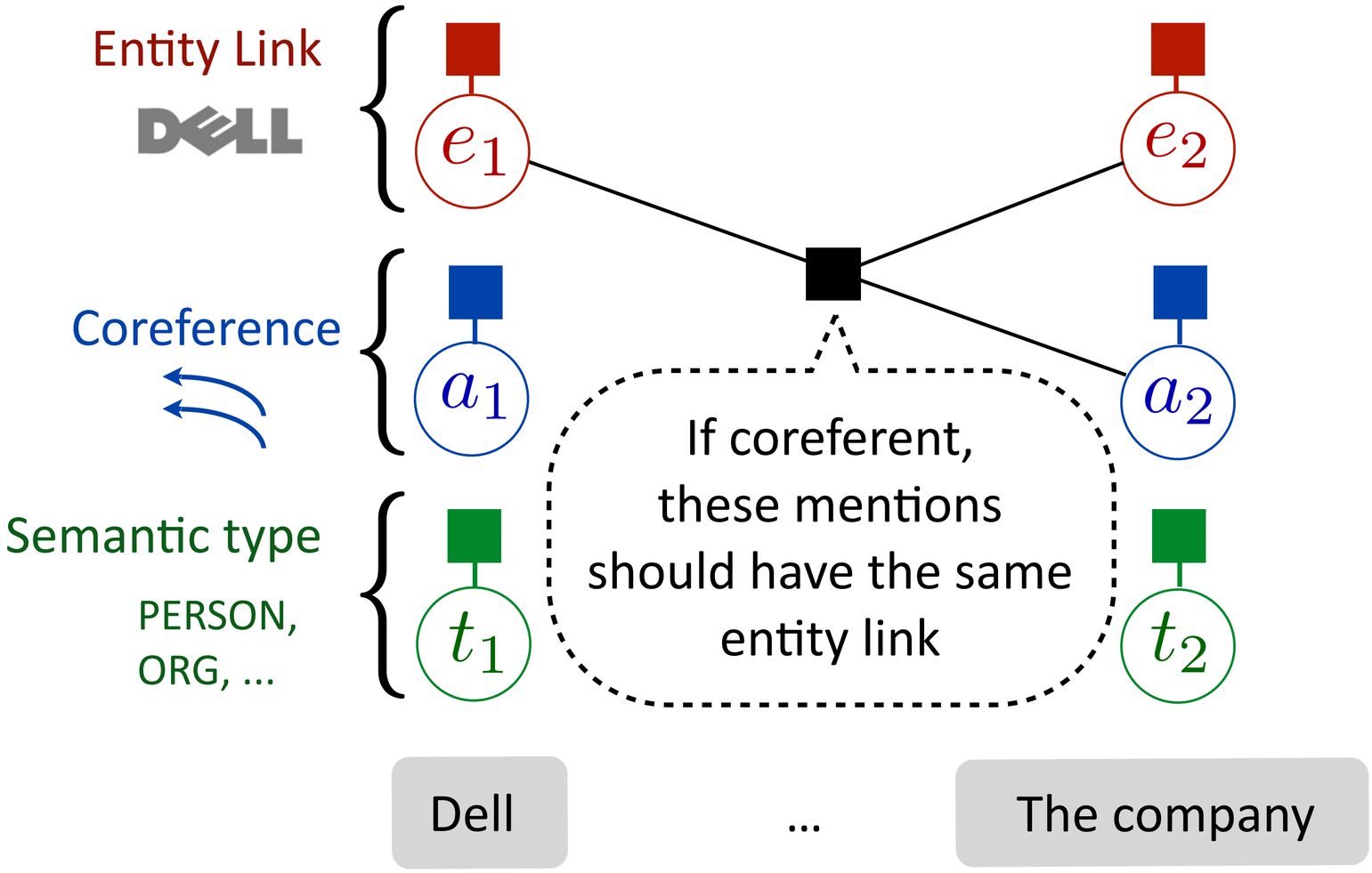
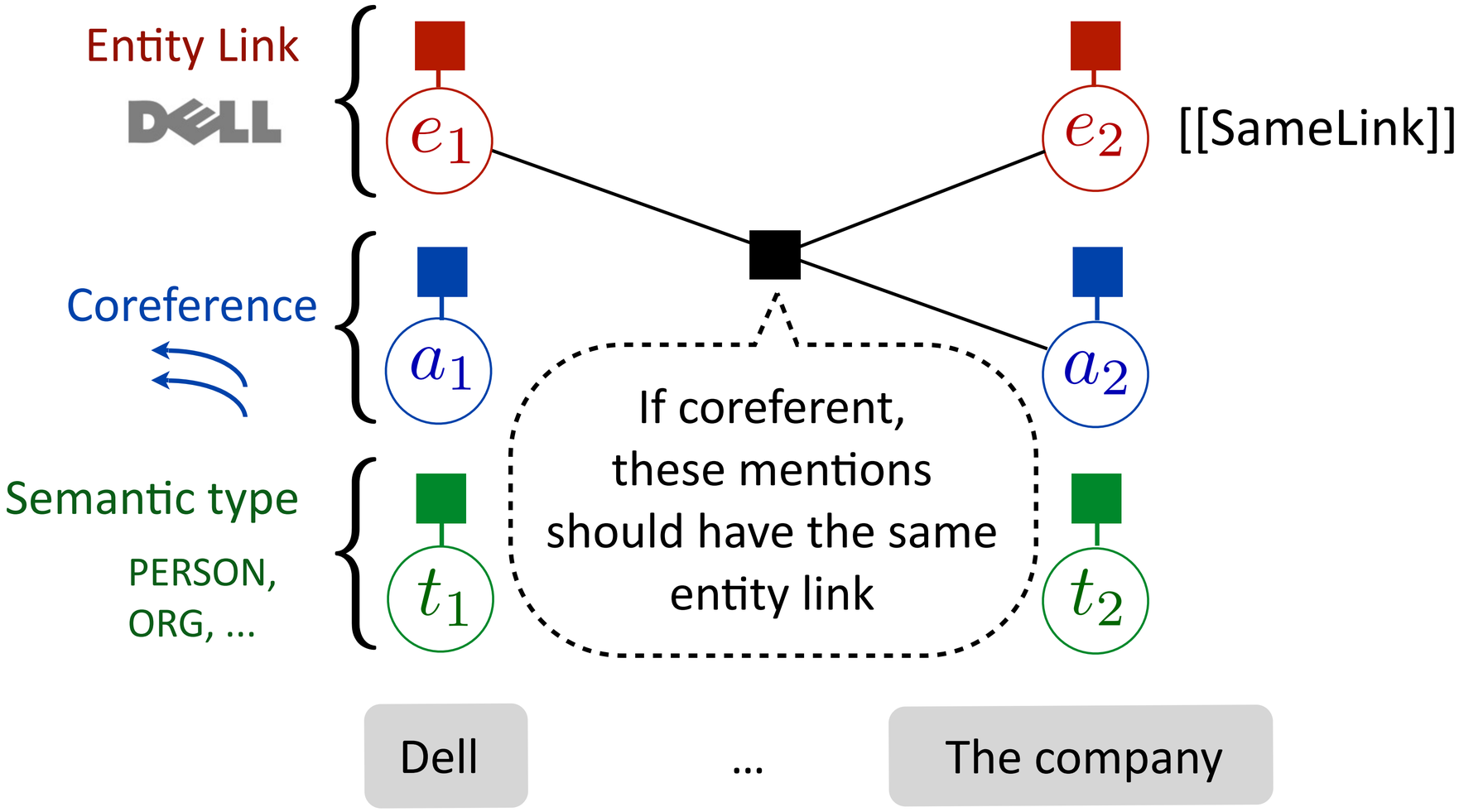


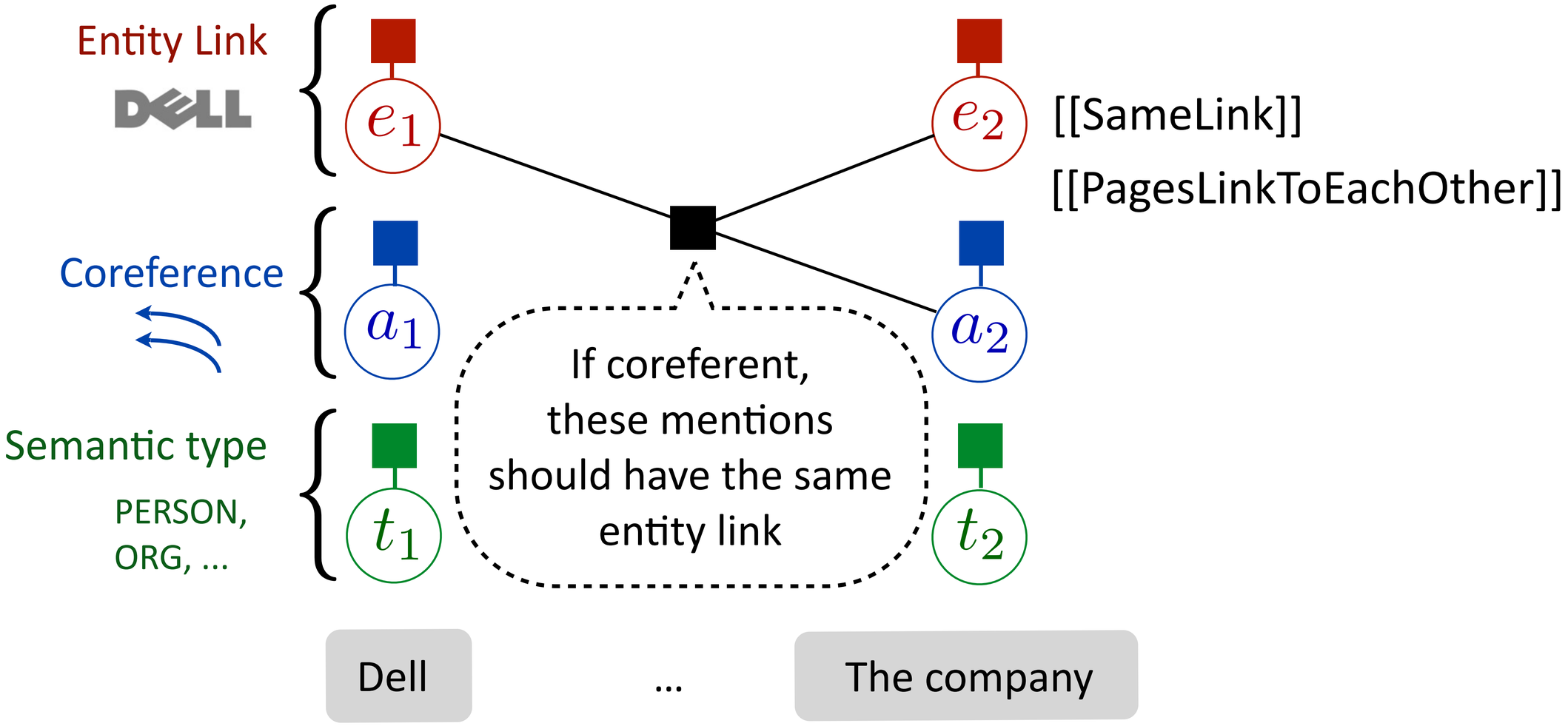
Coreference — Linking



Coreference — Linking



Coreference — Linking



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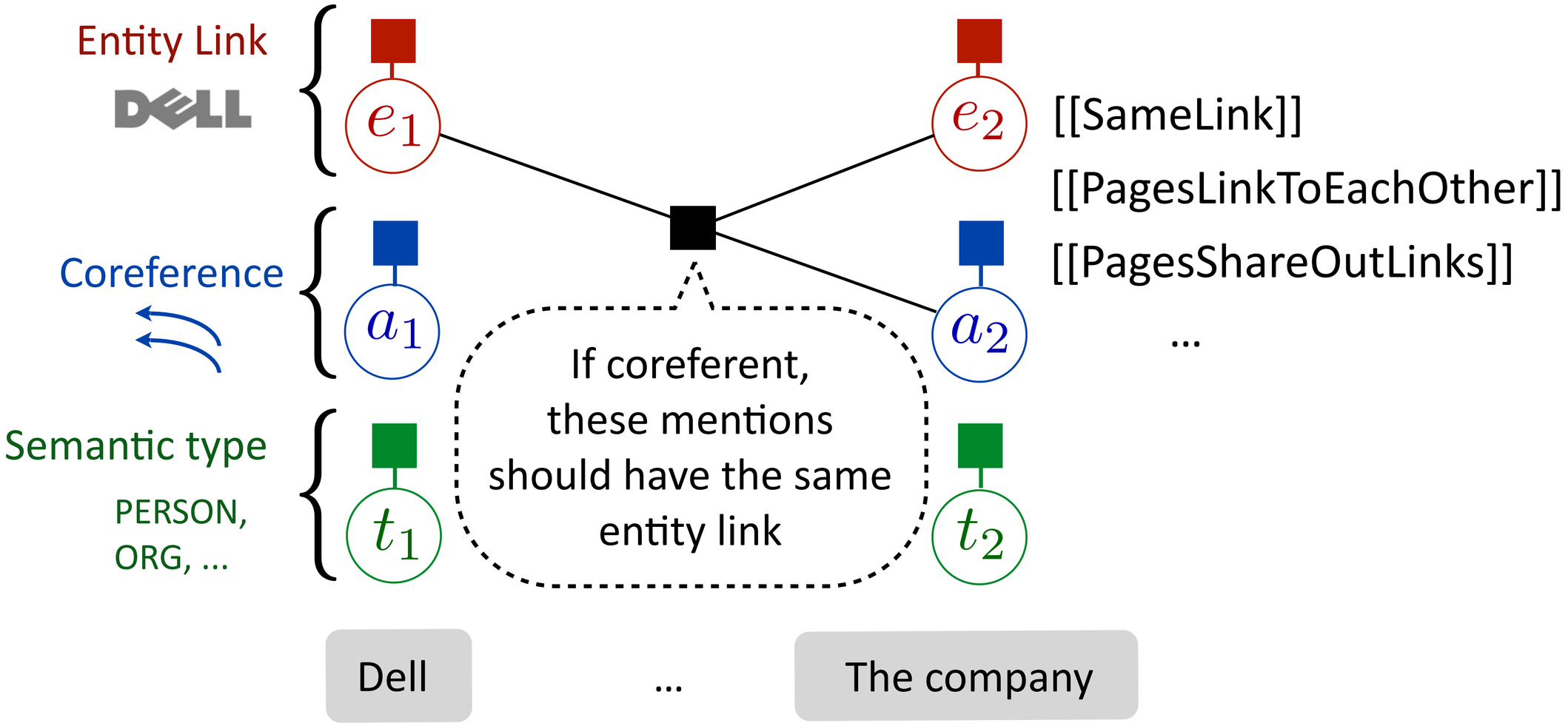
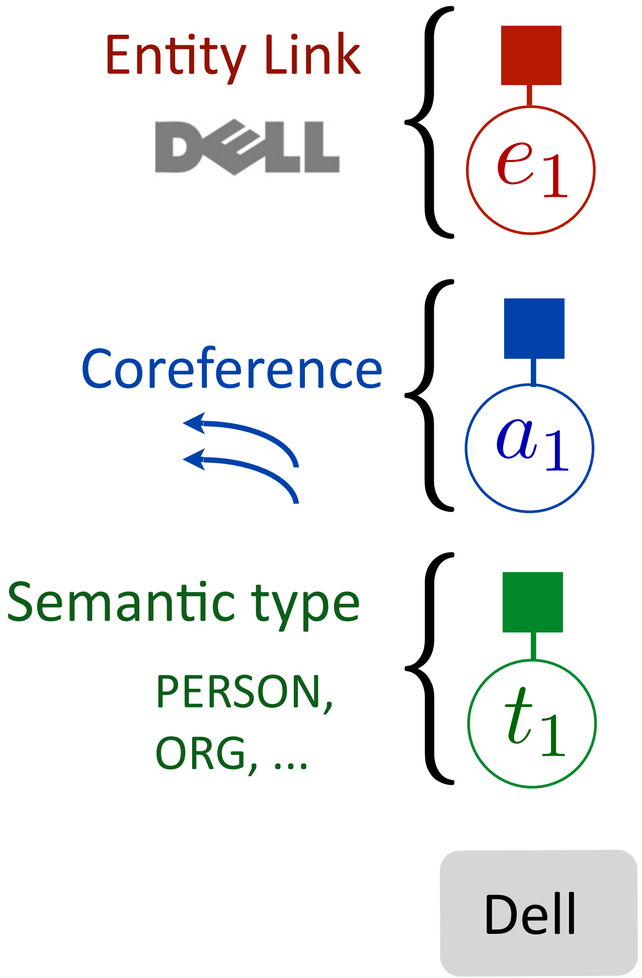


Typing — Linking



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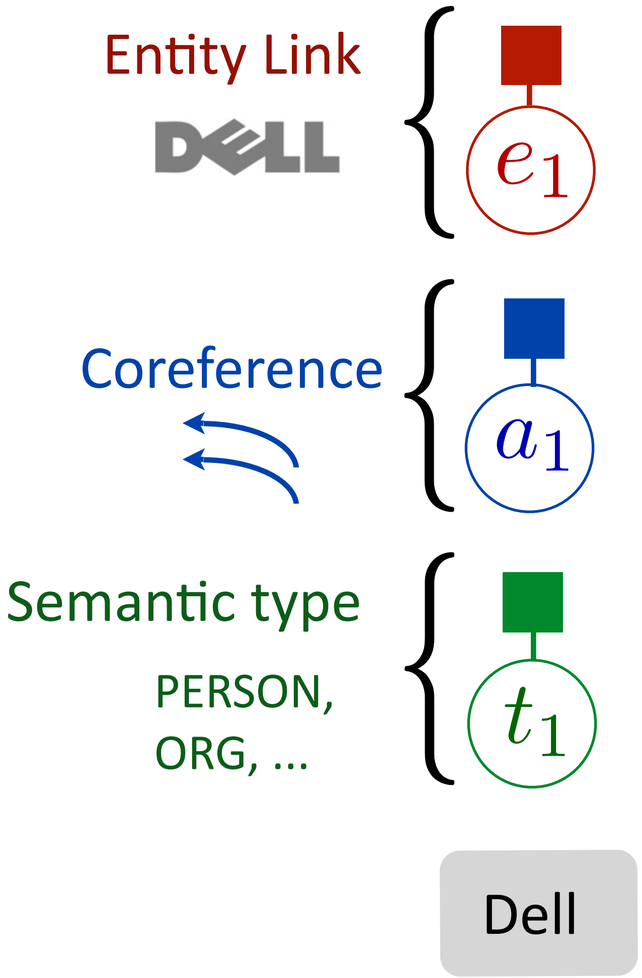

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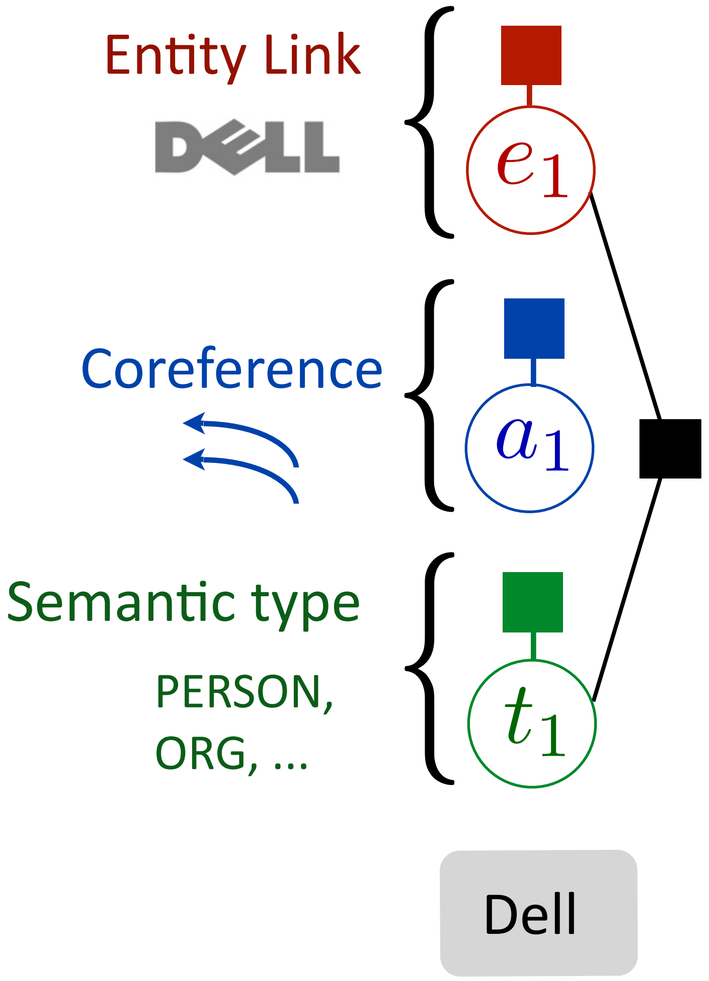

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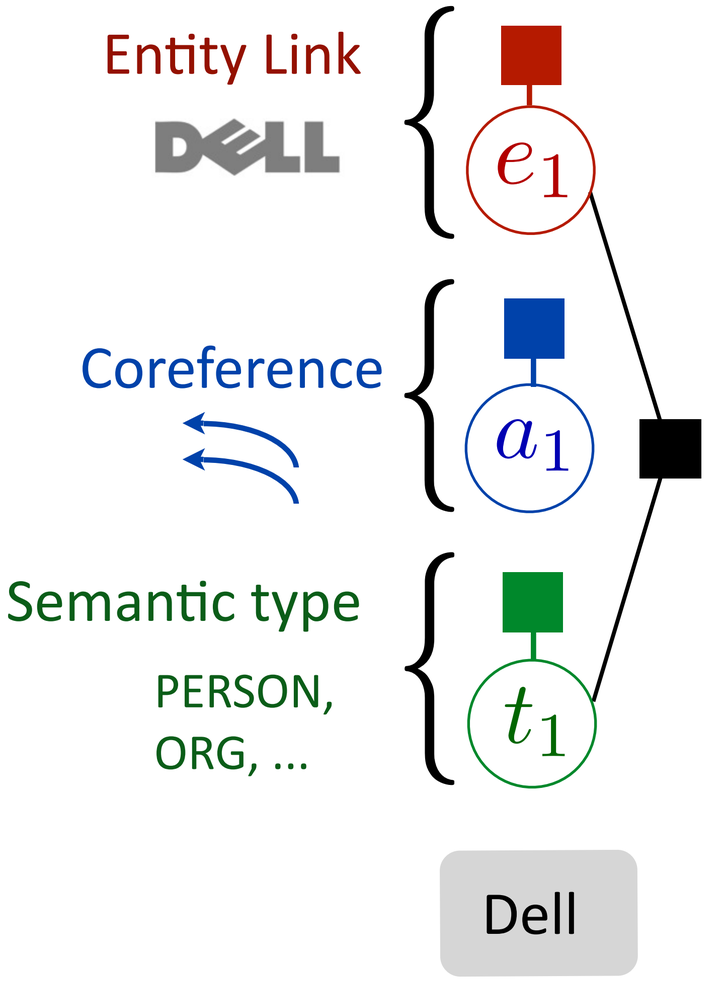
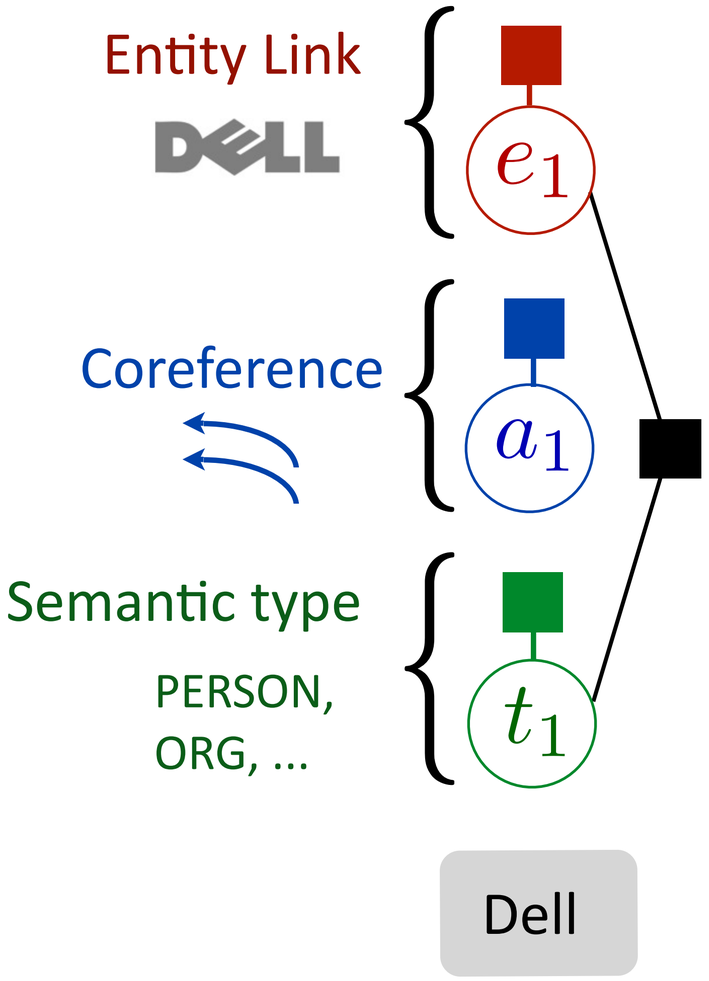


Dell

Dell Inc. is an American privately owned multinational computer technology company

Typing — Linking



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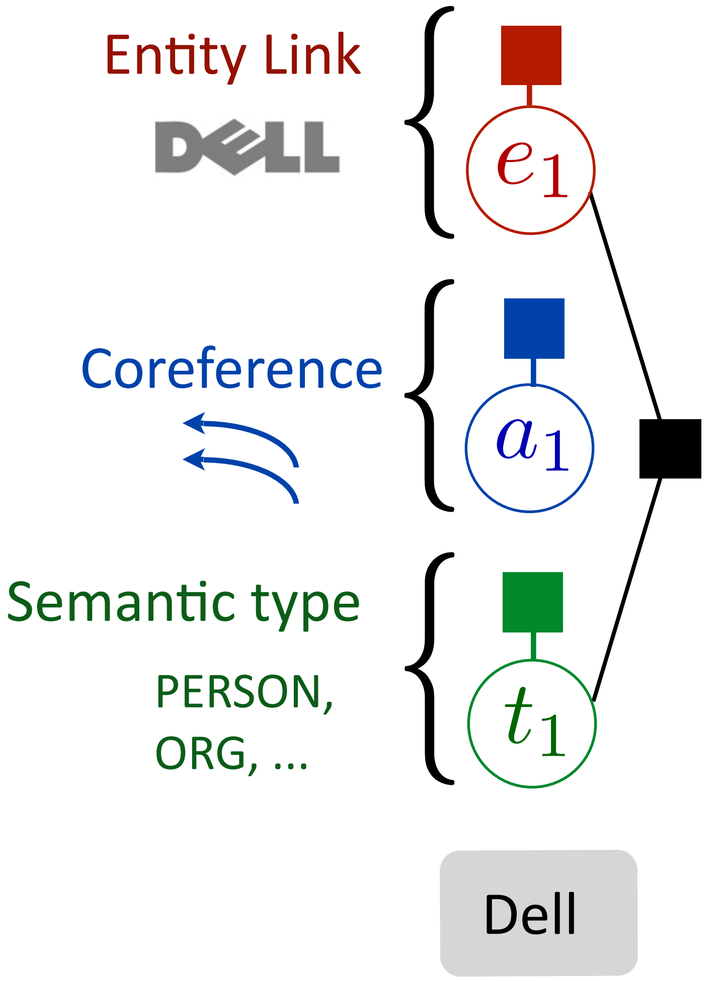
[[ORG $\wedge$ PredNom=*company*]]

Typing — Linking



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Dell Inc. is an American privately owned multinational computer technology company

Categories: Companies based in Austin, Texas

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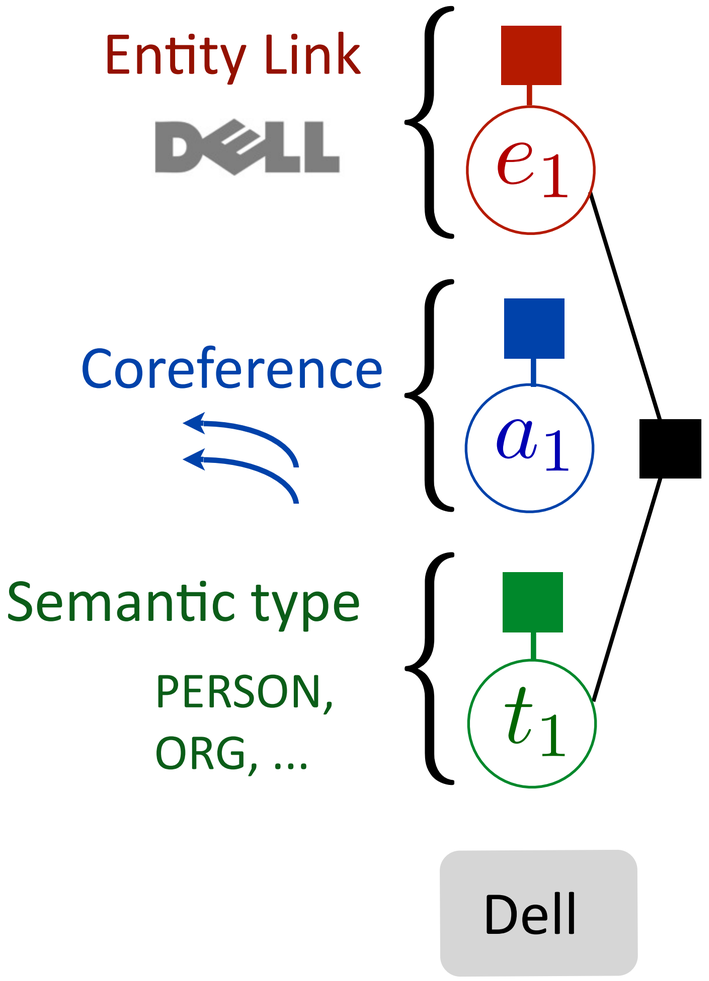
Typing — Linking



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[[ORG ∧ PredNom=*company*]]

[[ORG ∧ Category=*Companies*]]

...

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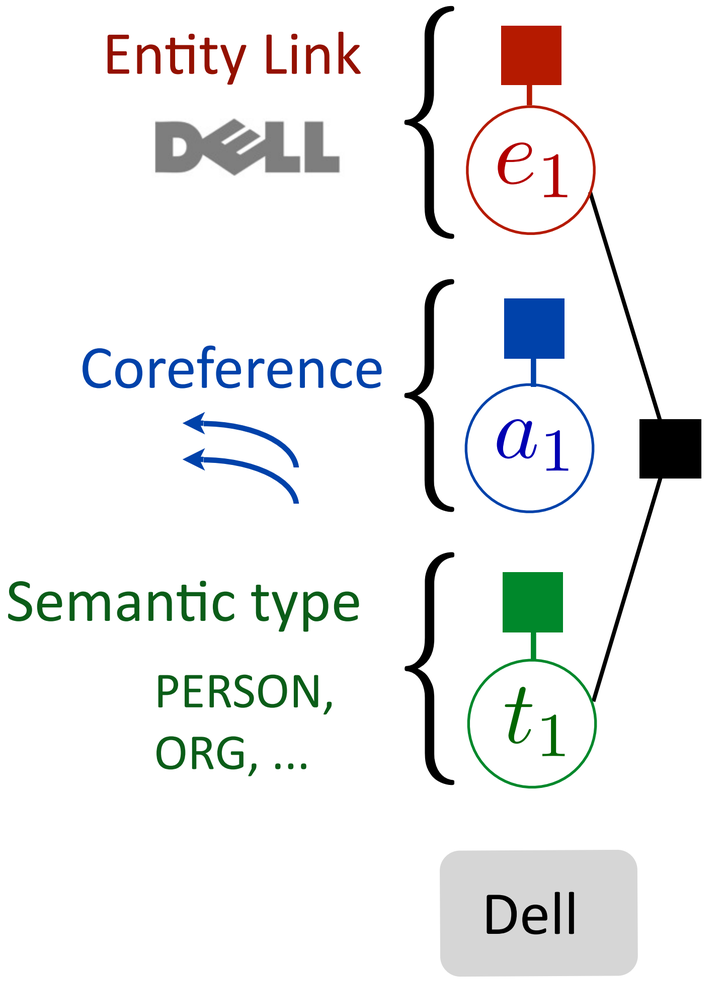

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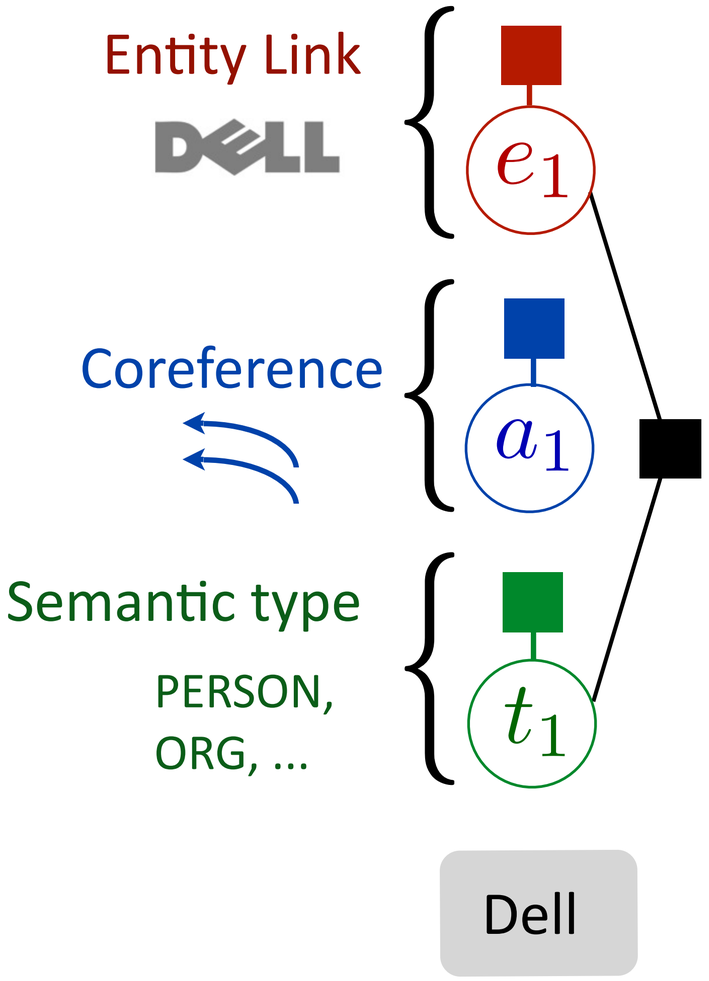
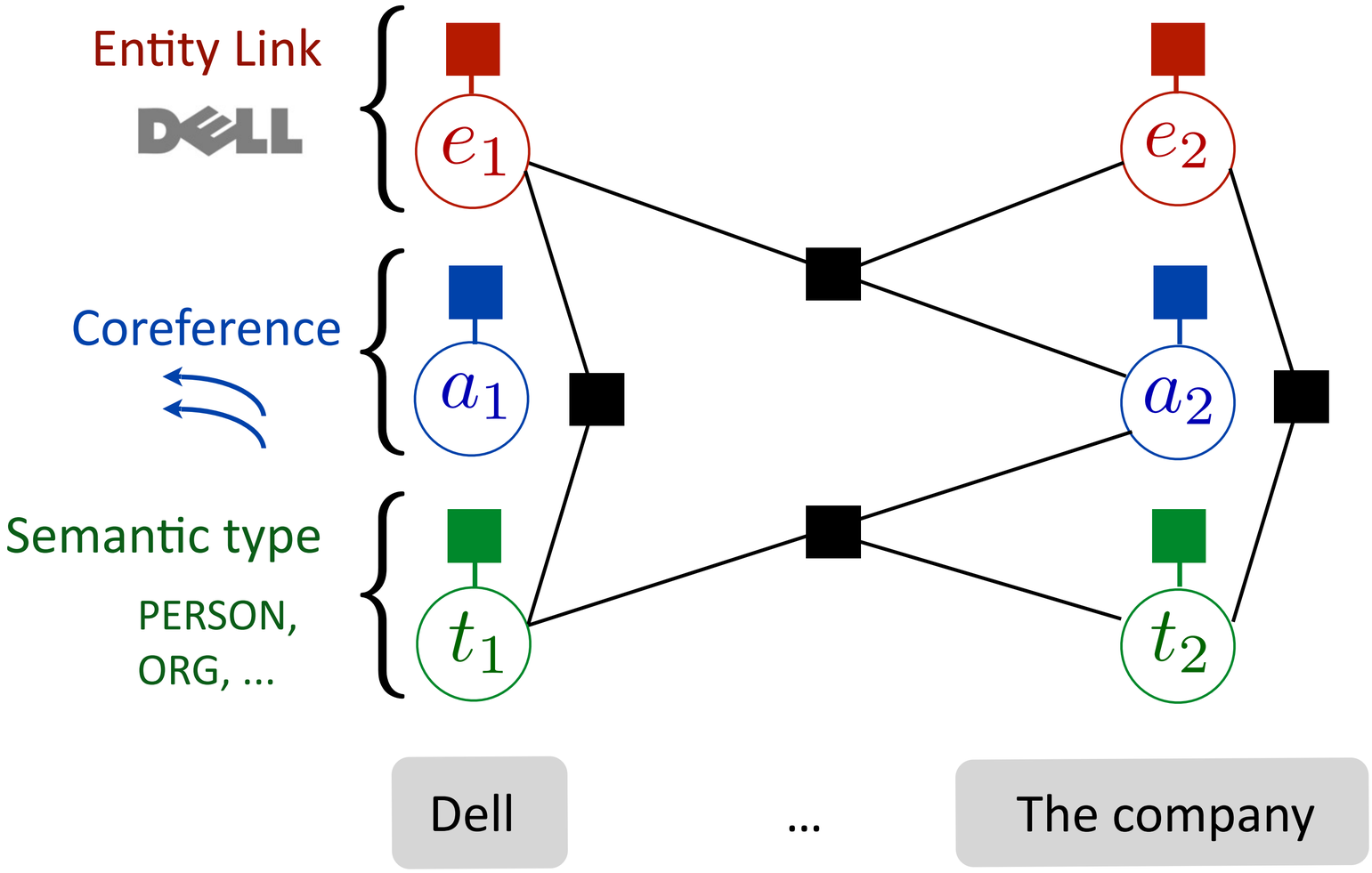


Joint Model


Entity Link
DELL
Coreference
Semantic type
PERSON,
ORG, ...
e_1
e_2
a_1
a_2
t_1
t_2
Dell
...
The company

Inference: Belief Propagation

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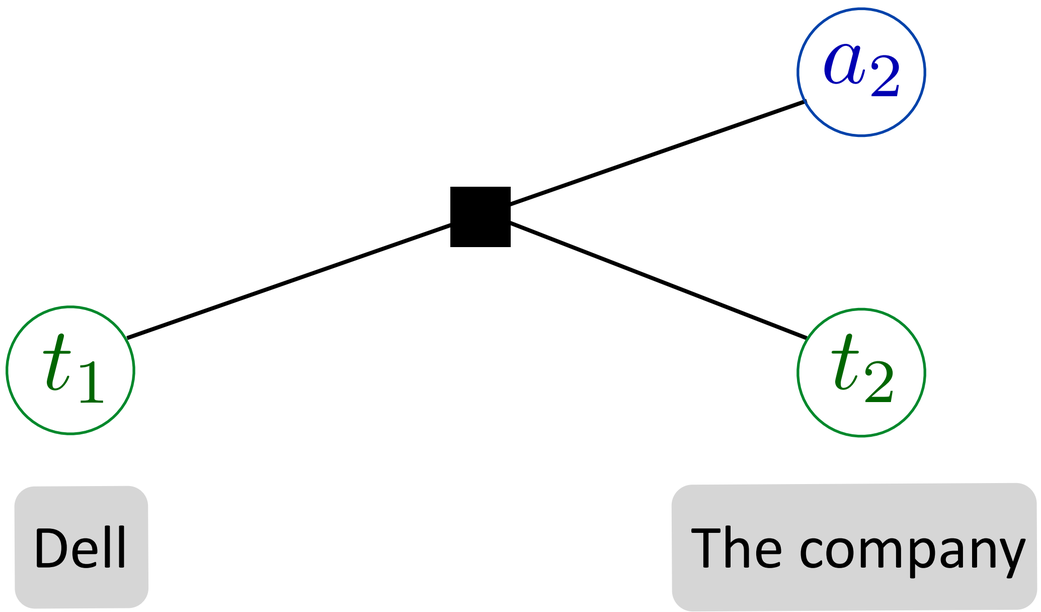
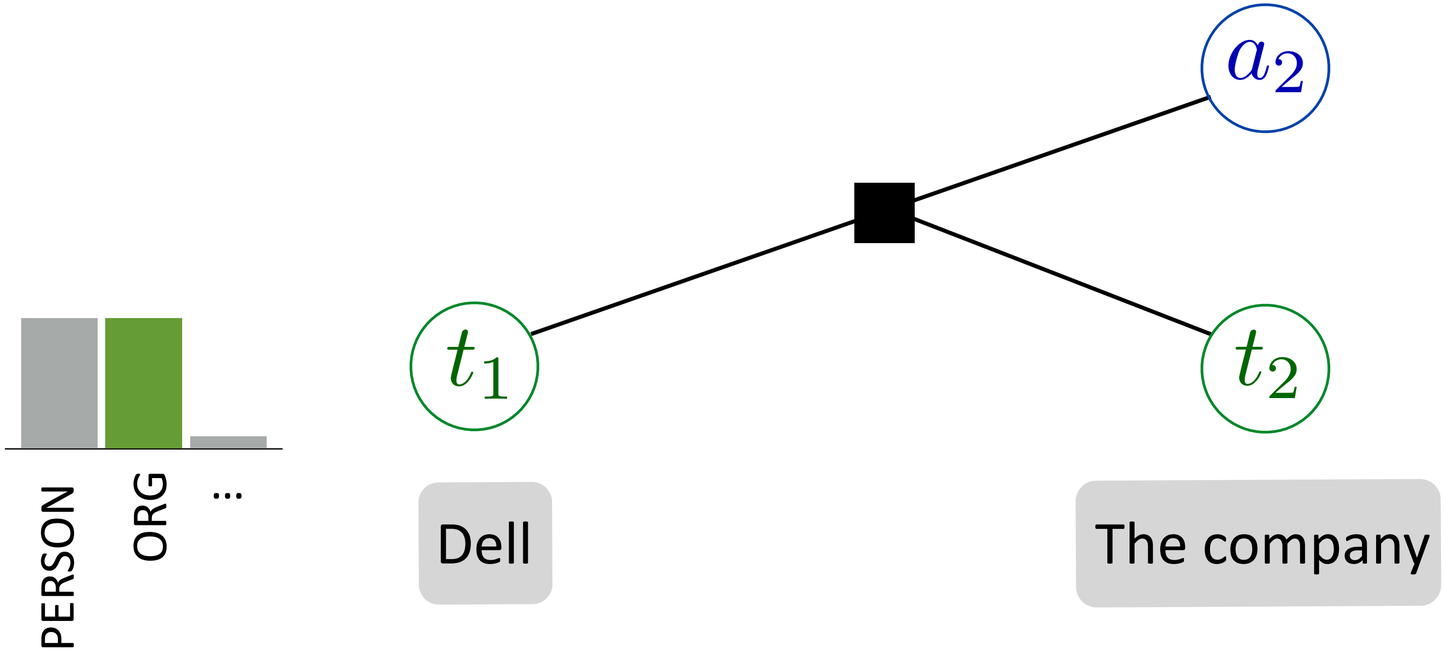


Inference: Belief Propagation



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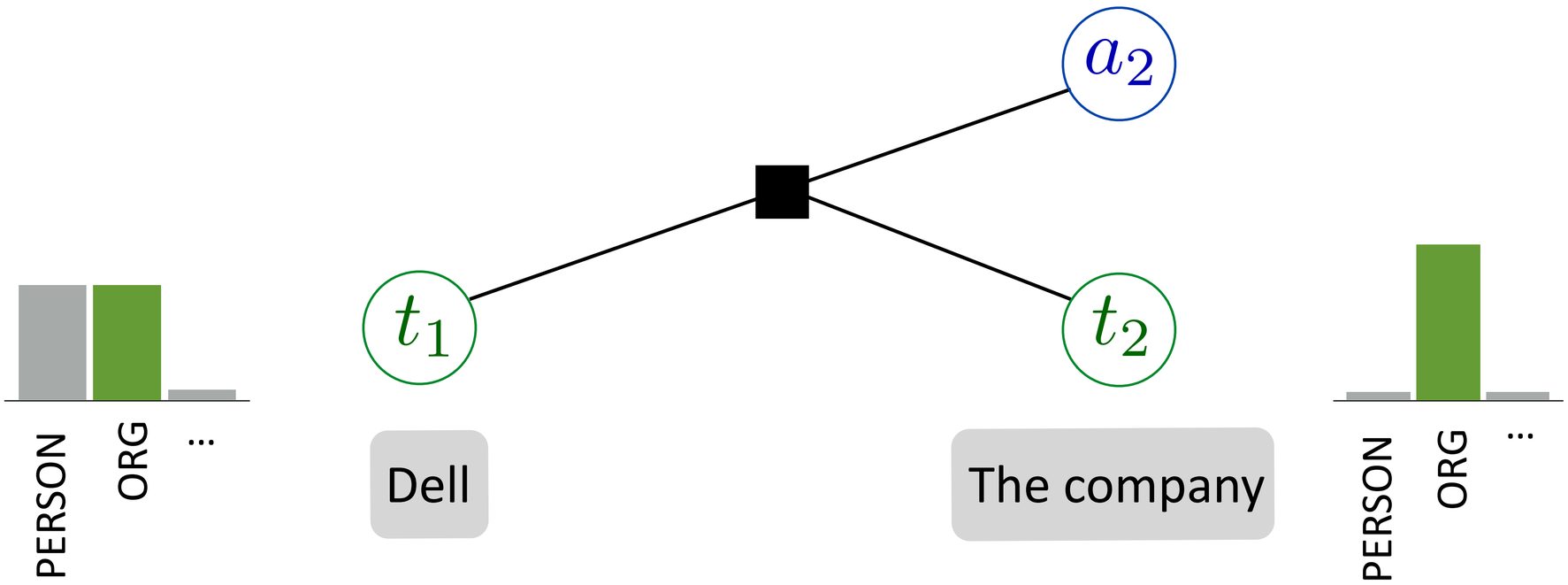
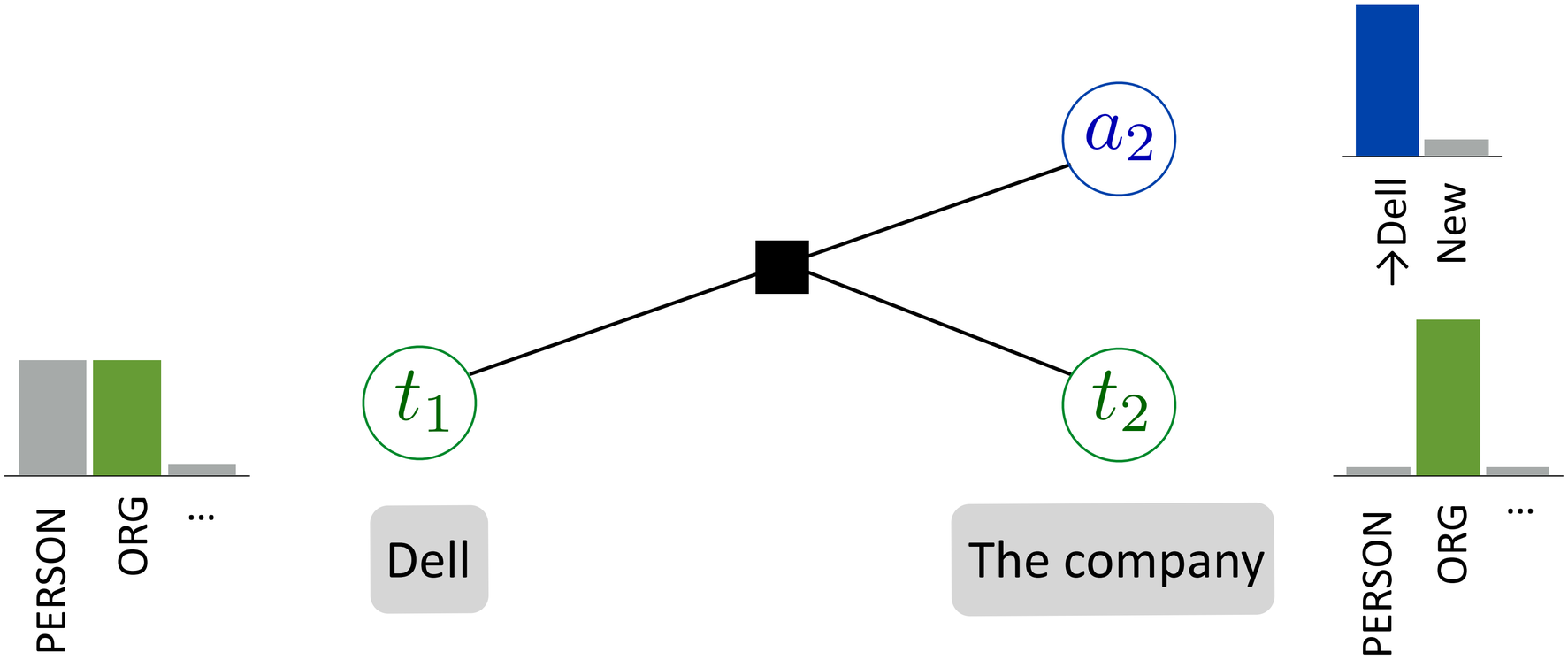


Inference: Belief Propagation



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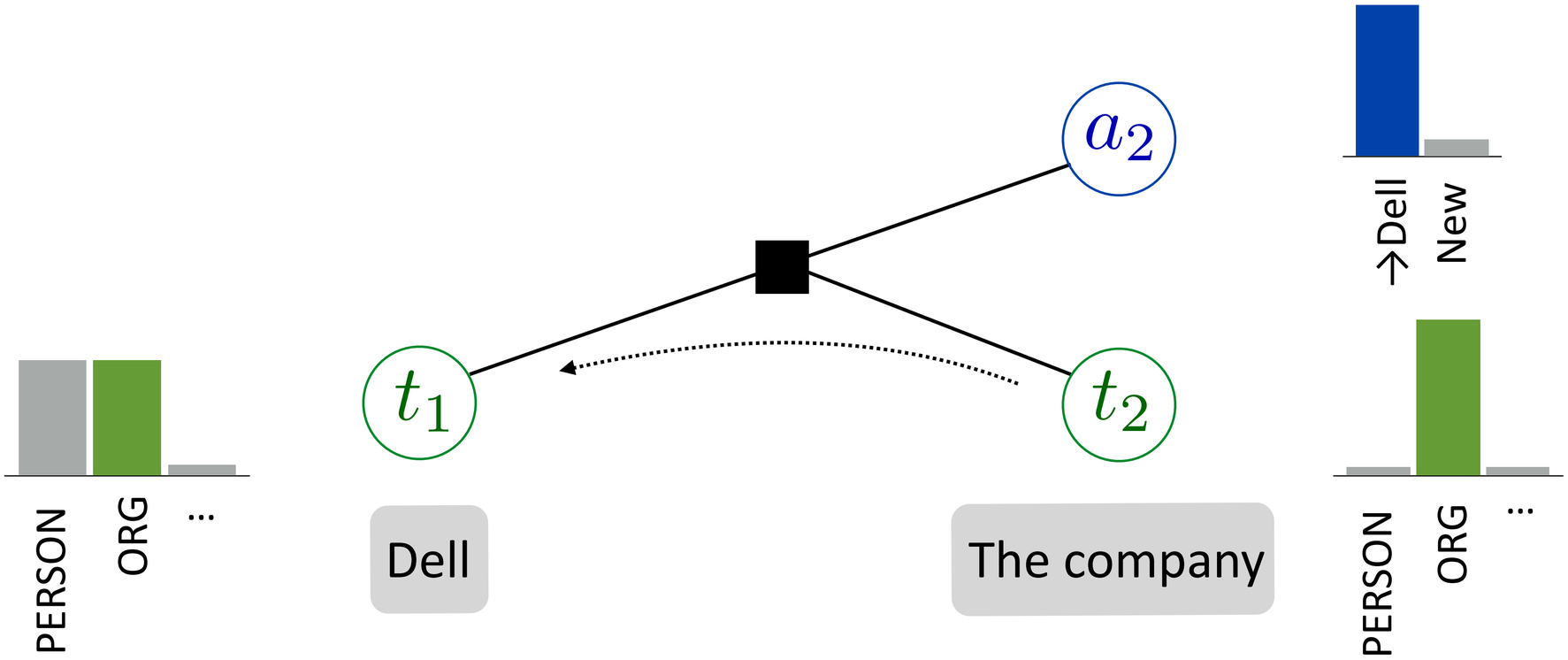

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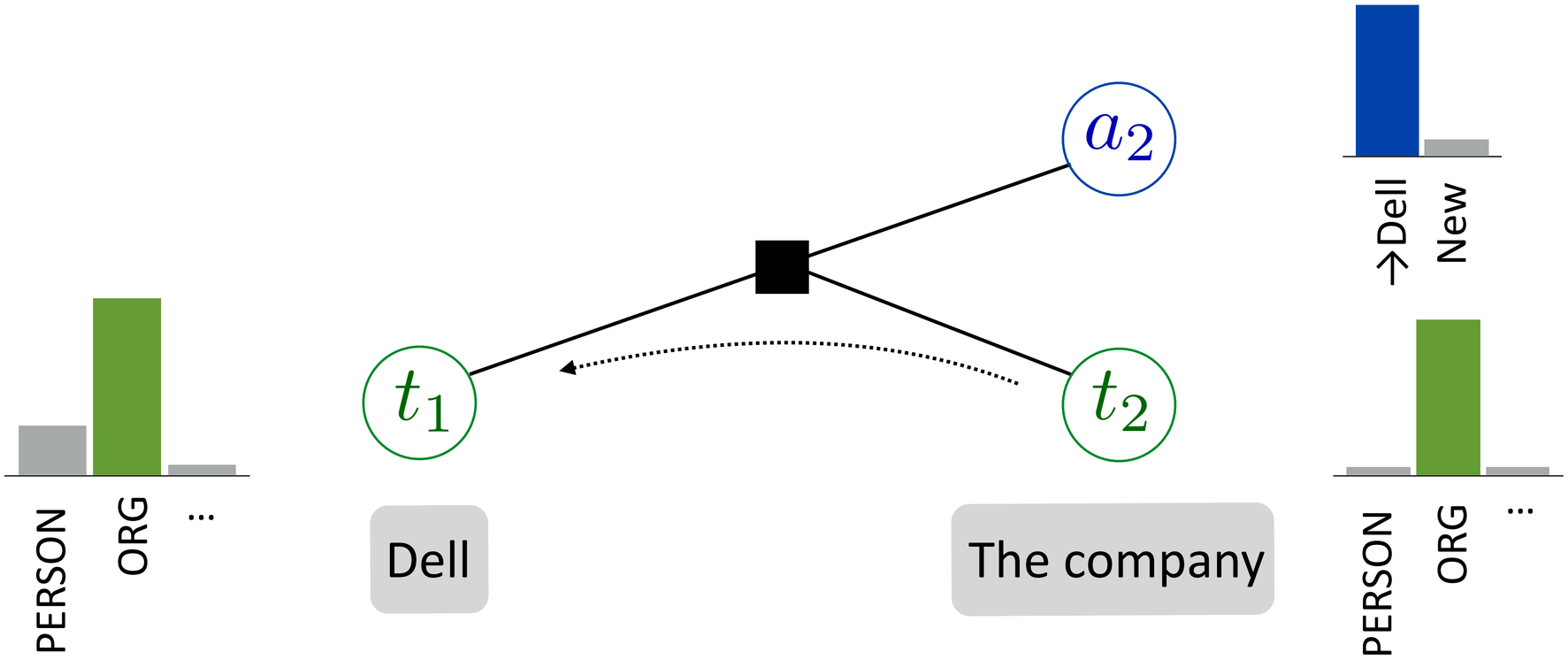

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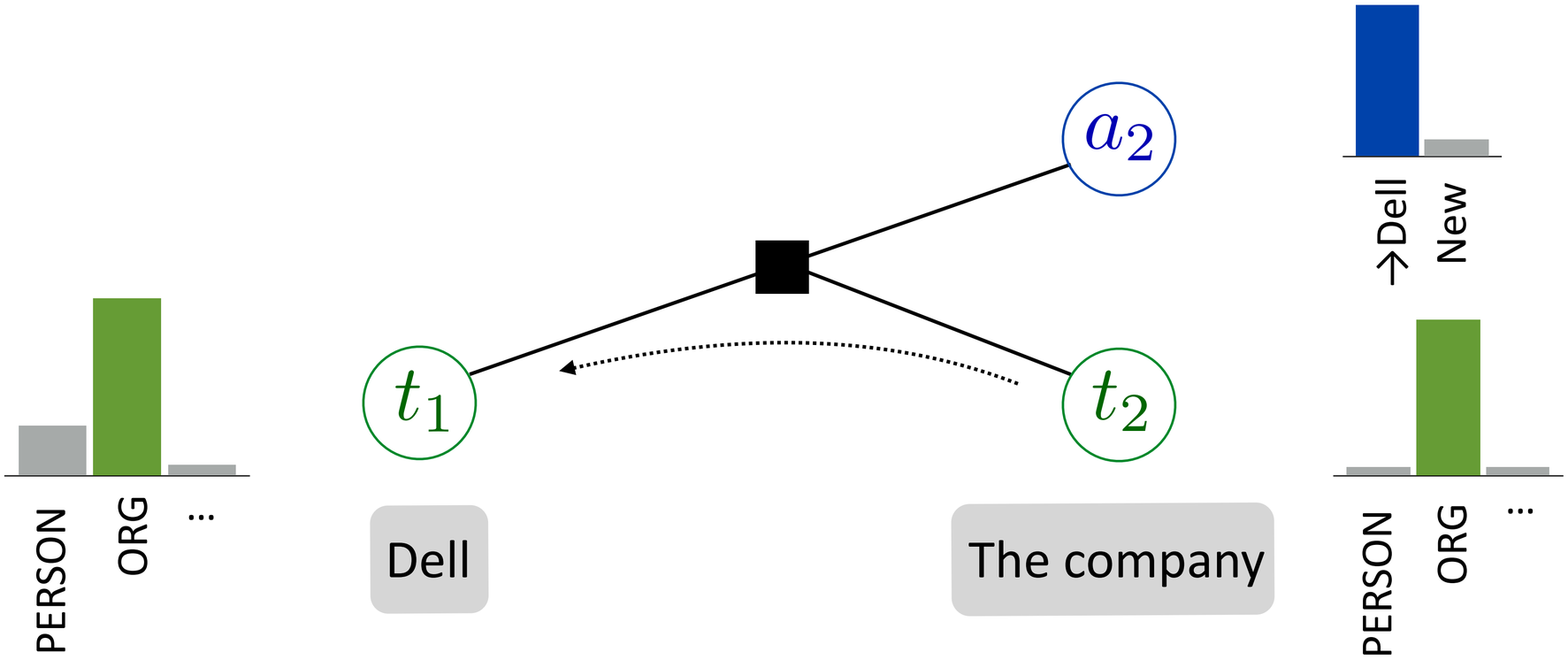

- BP encourages consensus among component models

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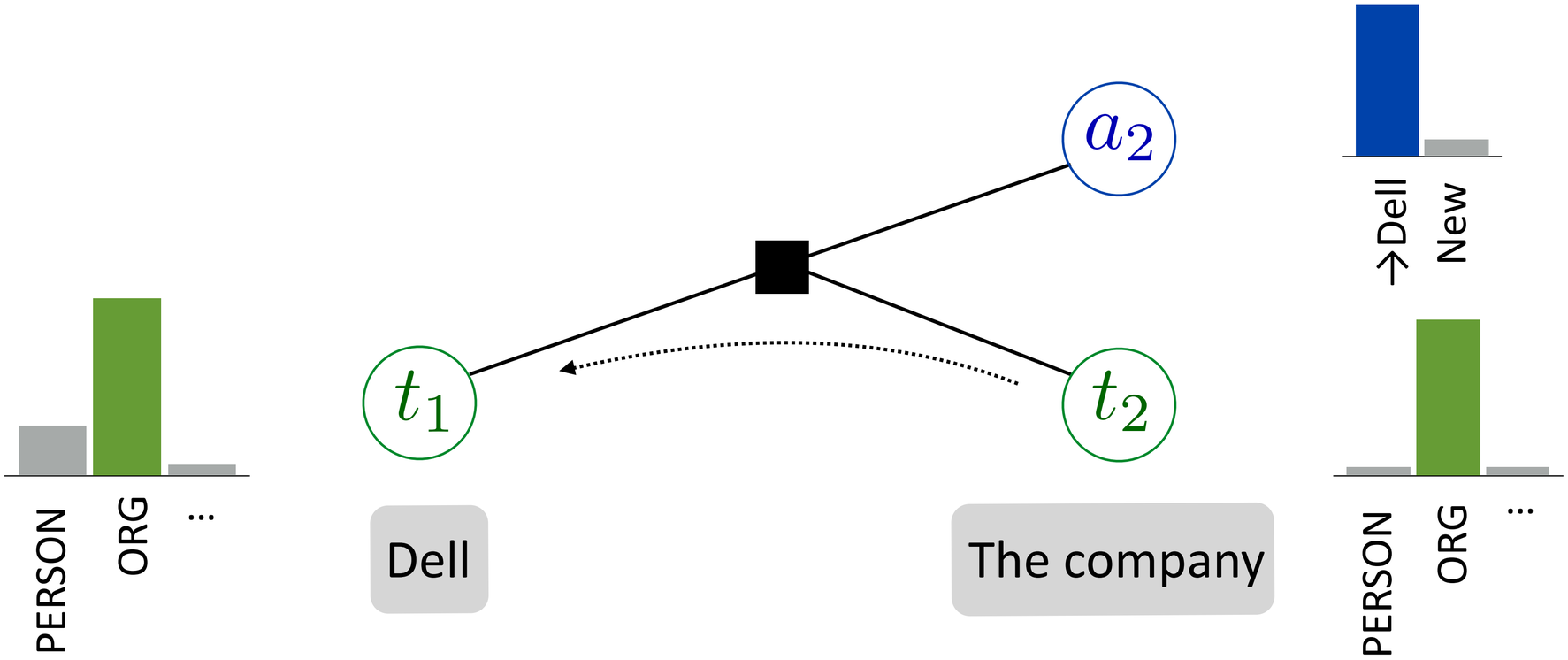

- BP encourages consensus among component models
- Use coarse pruning to reduce the number of coreference links

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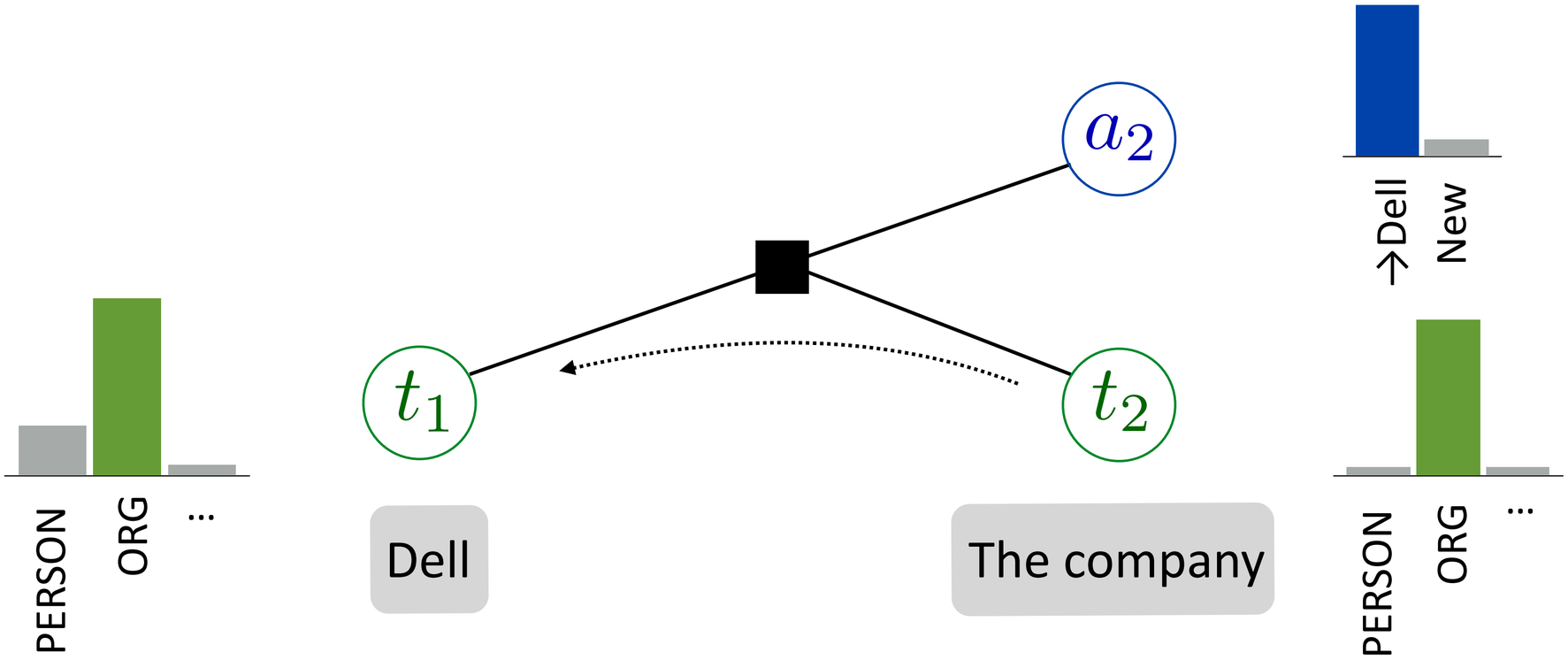

- BP encourages consensus among component models
- Use coarse pruning to reduce the number of coreference links
- Only ~2x slower than individual models, ~5 seconds / document

Learning

Learning

Maximize $\mathcal{L}(\theta) = \sum_{i=1}^{d} \log \sum_{\substack{\text{latent} \\ \text{stuff}}} \mathbf{p}(\mathbf{t}_i^*, \mathbf{a}_i^*, \mathbf{e}_i^* | \mathbf{x}; \mathbf{w})$

Learning

Maximize $\mathcal{L}(\theta) = \sum_{i=1}^{d} \log \sum_{\substack{\text{latent} \\ \text{stuff}}} \mathbf{p}(\mathbf{t}_i^*, \mathbf{a}_i^*, \mathbf{e}_i^* | \mathbf{x}; \mathbf{w}) - \lambda \|\theta\|_1$

Learning

Maximize $\mathcal{L}(\theta) = \sum_{i=1}^{d} \log \sum_{\substack{\text{latent} \\ \text{stuff}}} \mathbf{p}(\mathbf{t}_i^*, \mathbf{a}_i^*, \mathbf{e}_i^* | \mathbf{x}; \mathbf{w}) - \lambda \|\theta\|_1$

$$\mathbf{p}'(\mathbf{t}_i, \mathbf{a}_i, \mathbf{e}_i | \mathbf{x}; \mathbf{w})) \propto \mathbf{p}(\mathbf{t}_i, \mathbf{a}_i, \mathbf{e}_i | \mathbf{x}; \mathbf{w}) \exp\left(\alpha_t \ell(\mathbf{t}) + \alpha_a \ell(\mathbf{a}) + \alpha_e \ell(\mathbf{e})\right)$$

task-specific loss functions

[Gimpel and Smith, 2010]

Related Work

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- Joint coreference and entity linking

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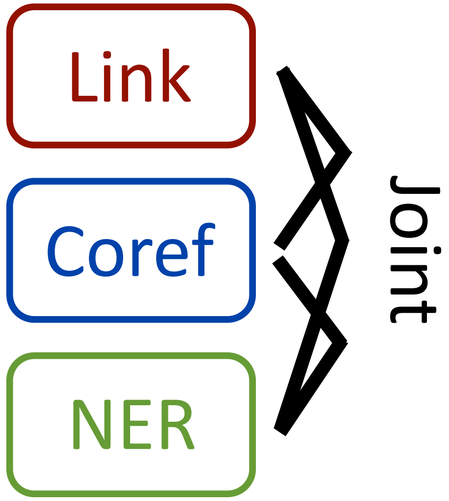
- Joint coreference, NER, and relation extraction: Singh et al (2013)

Outline

- Model
  - Independent models (unary, per-task factors)
  - Joint coupling (higher-arity, cross-task factors)
- Experiments



Data

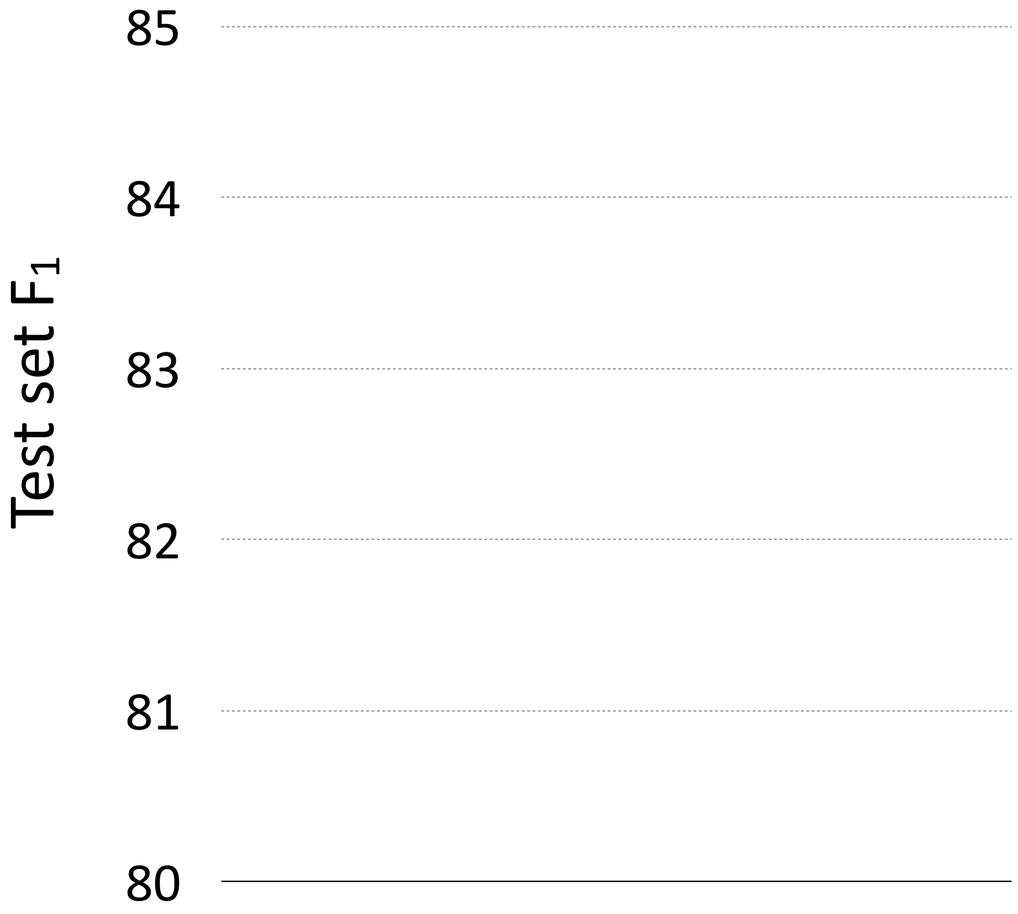
Data

- OntoNotes 5 (4000 docs): NER and coreference, no entity links

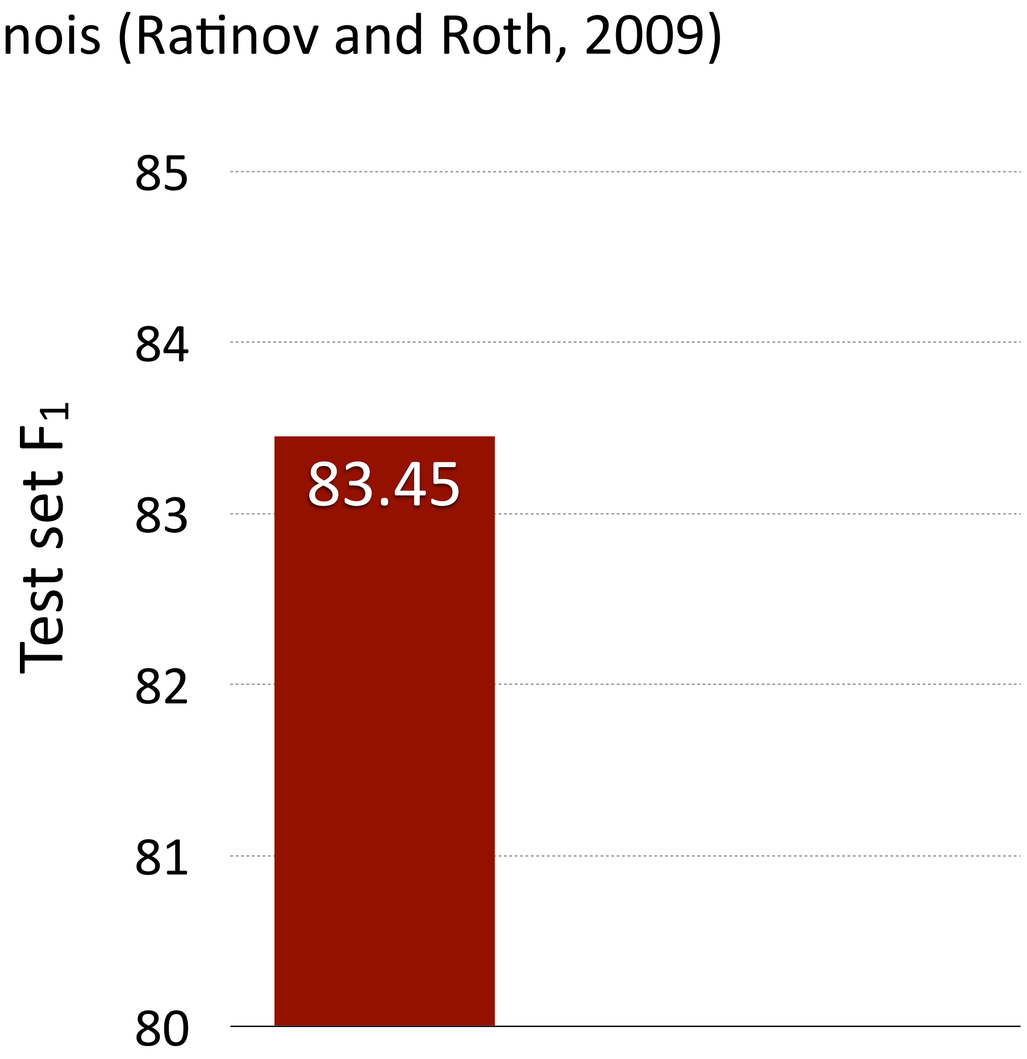
Data

- OntoNotes 5 (4000 docs): NER and coreference, no entity links
- ACE 2005 (600 docs): NER, coreference, entity links

NER (OntoNotes)



NER (OntoNotes)



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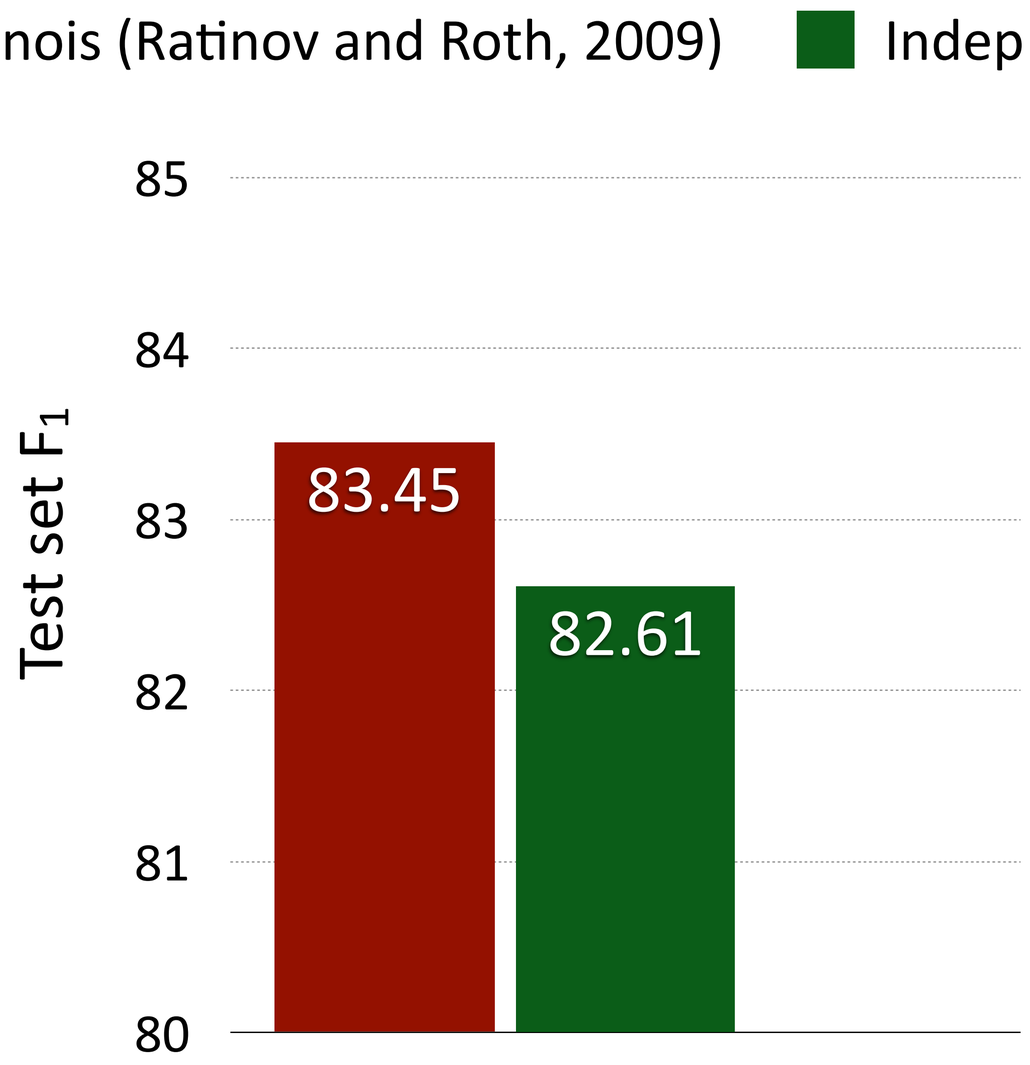

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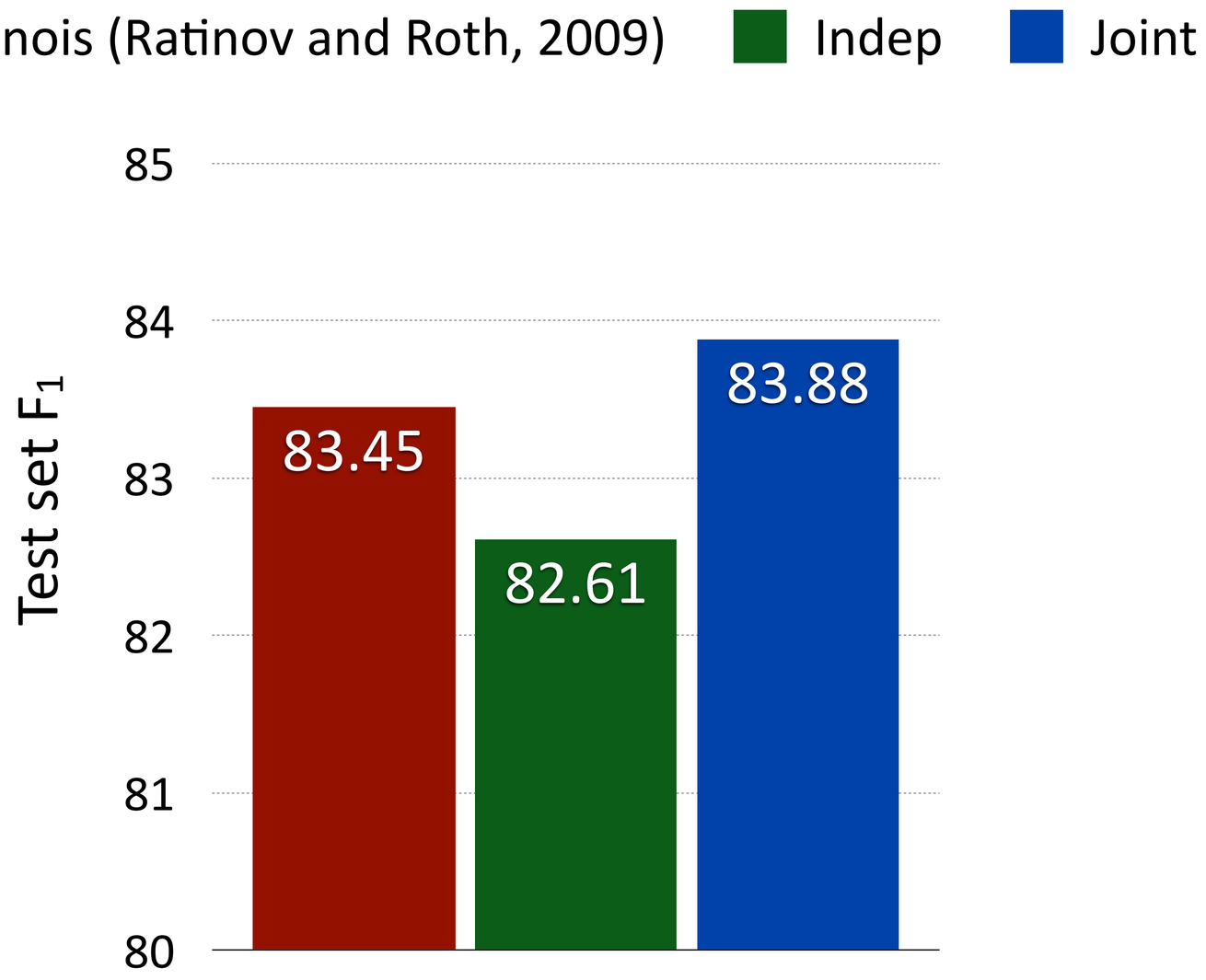
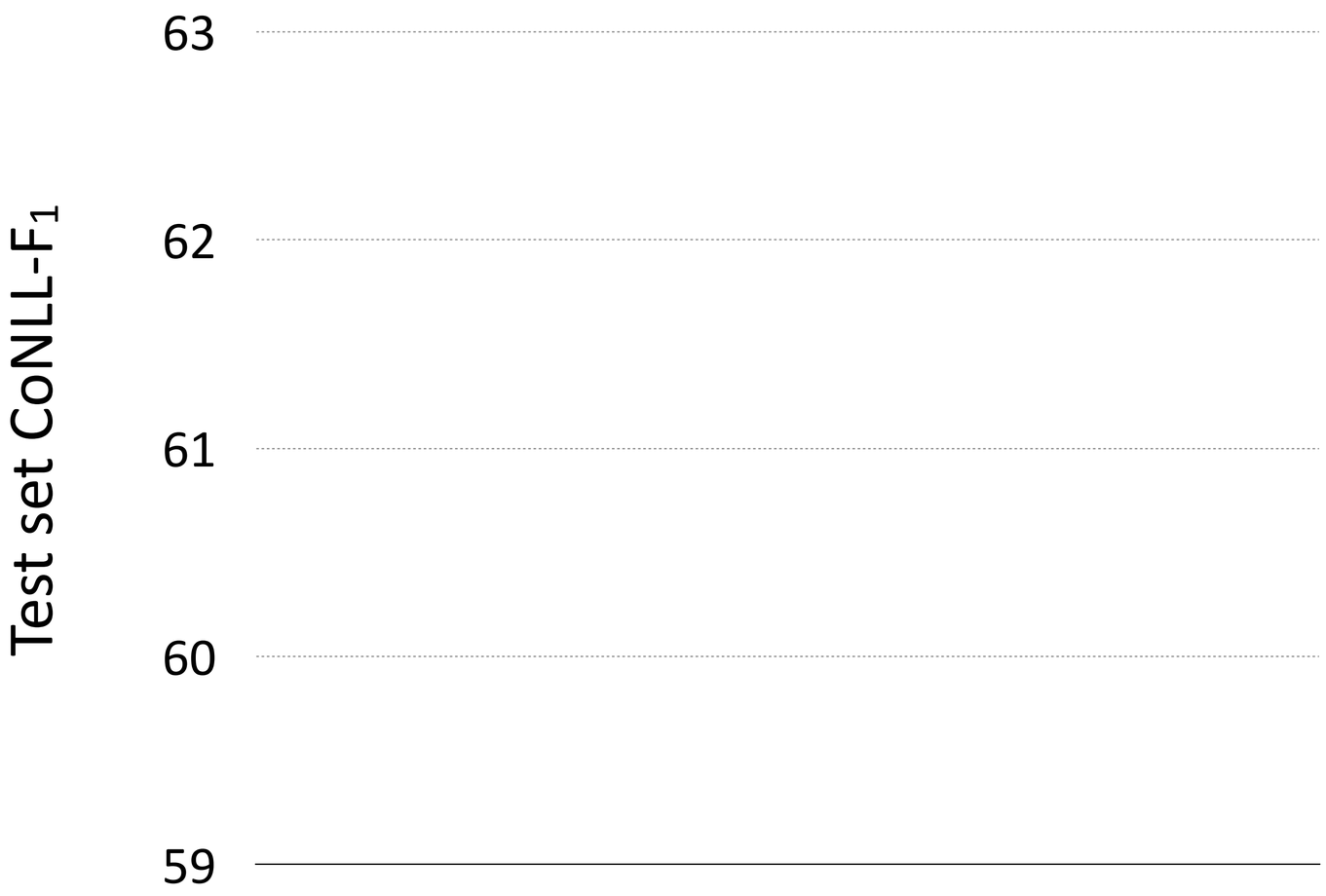


Coreference (OntoNotes)



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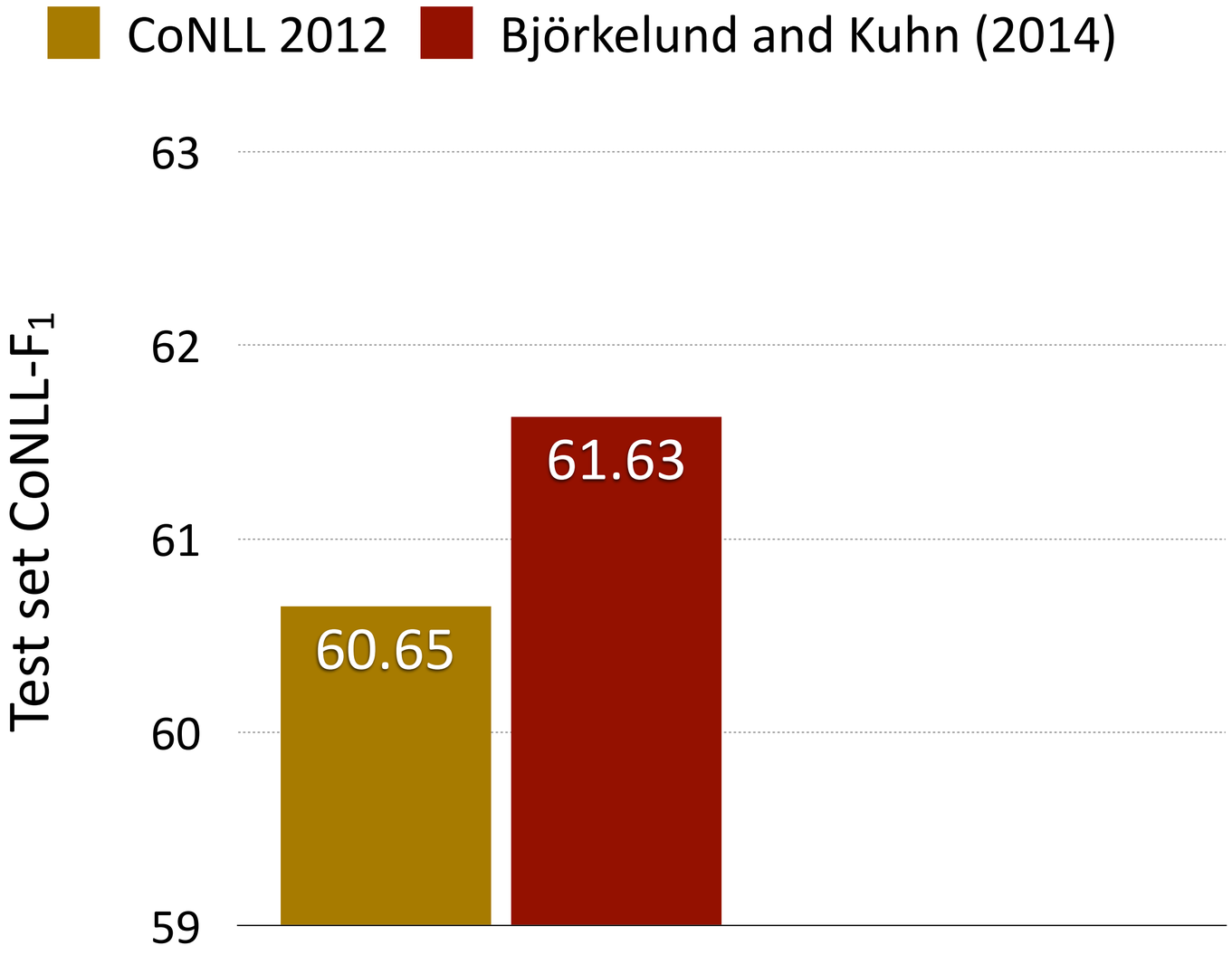
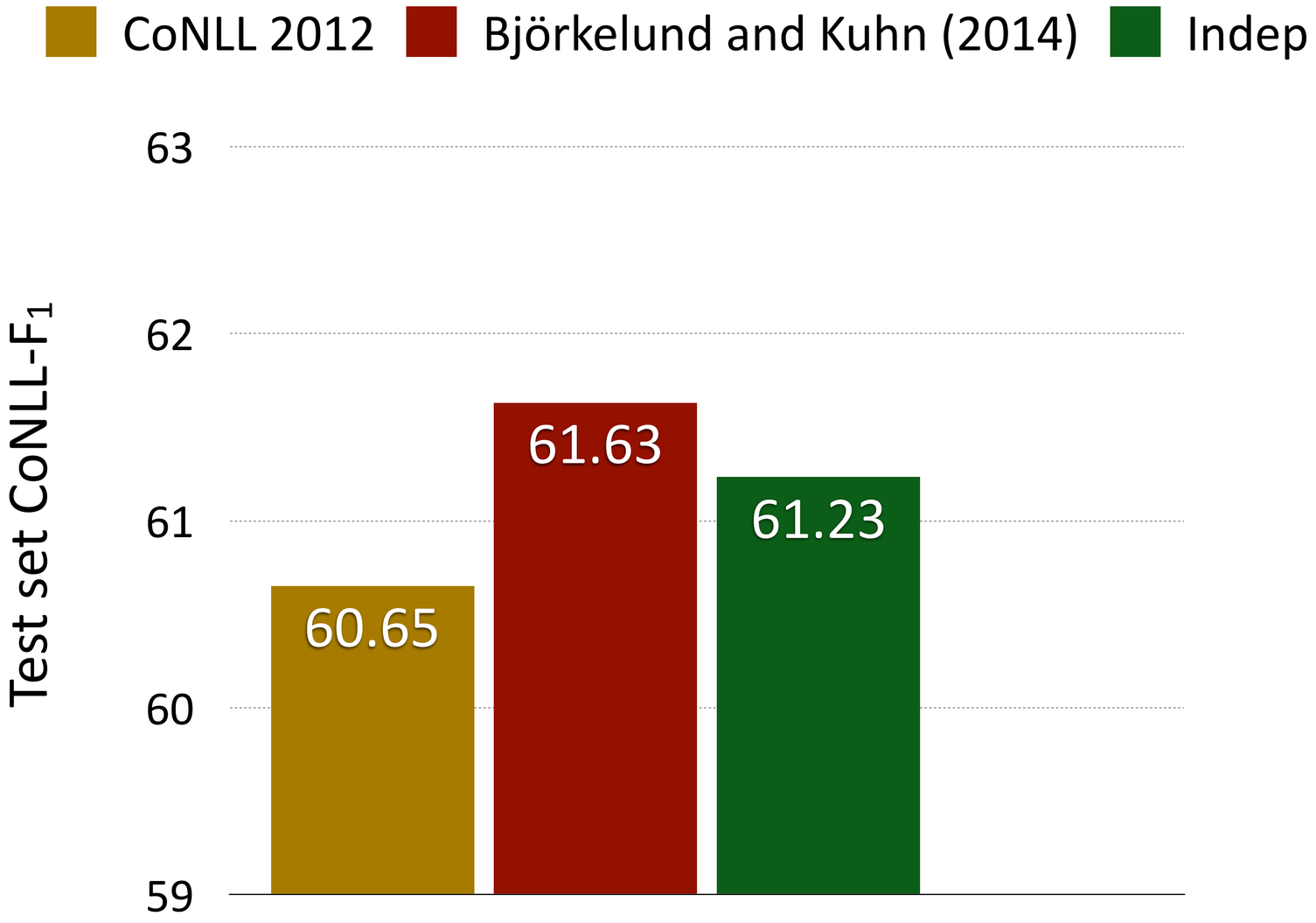


Coreference (OntoNotes)



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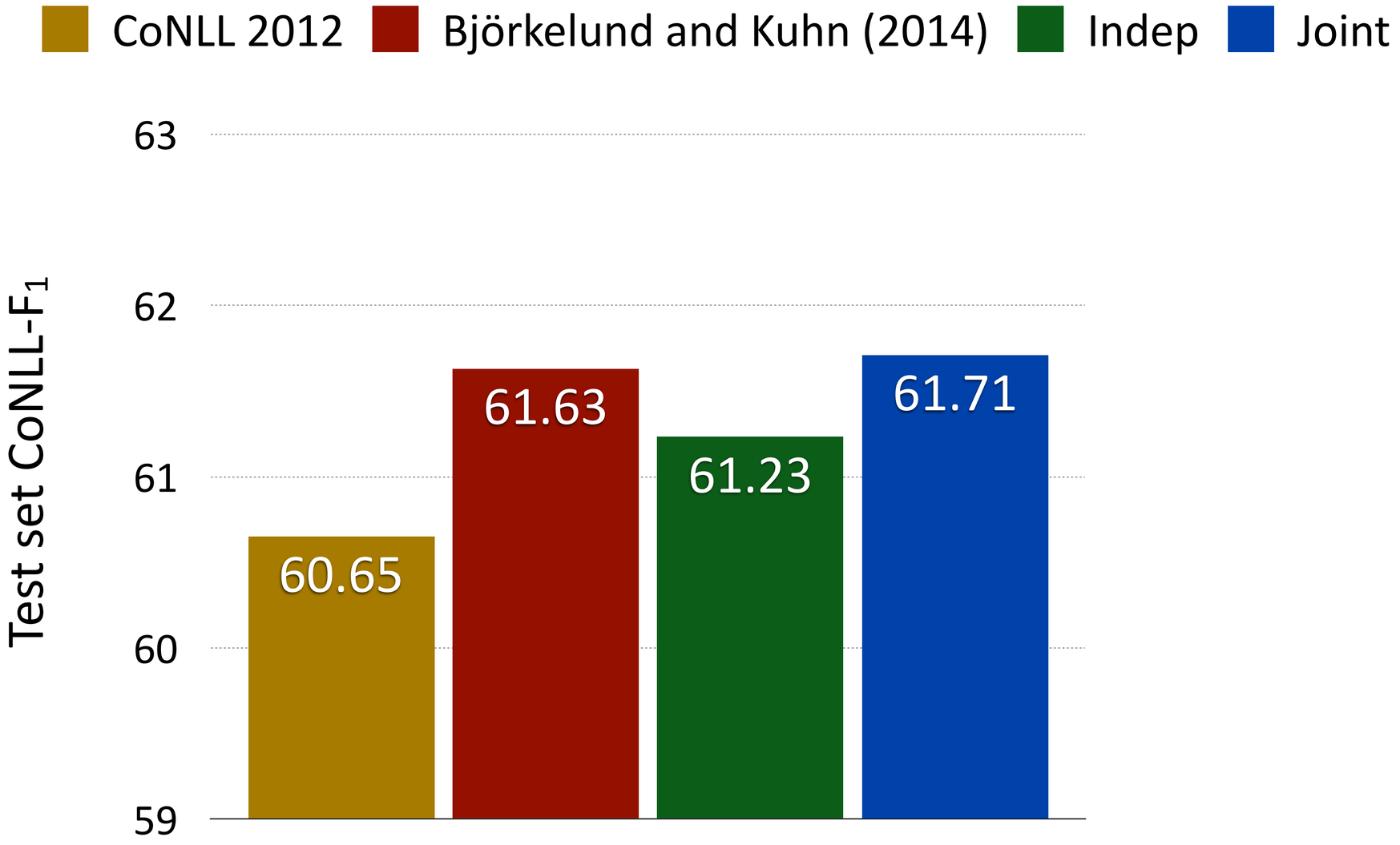
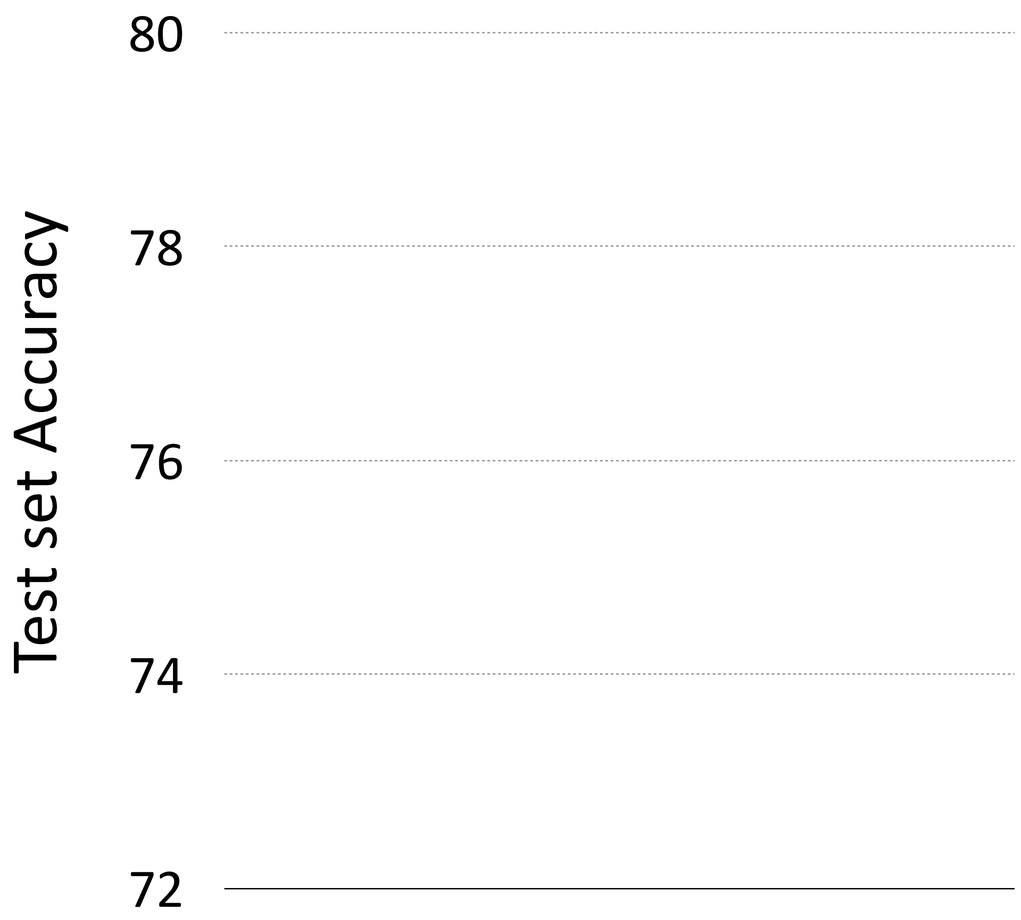


Entity Linking (ACE)



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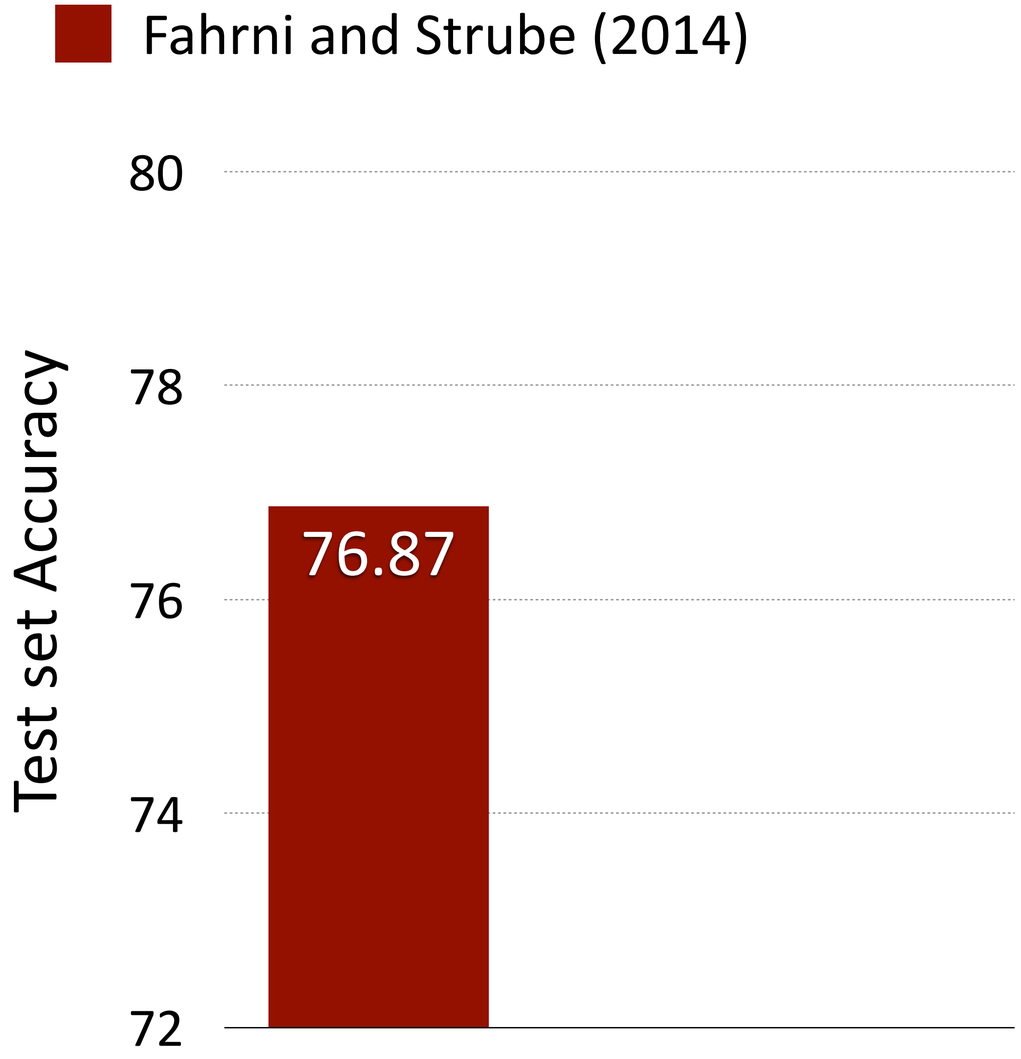

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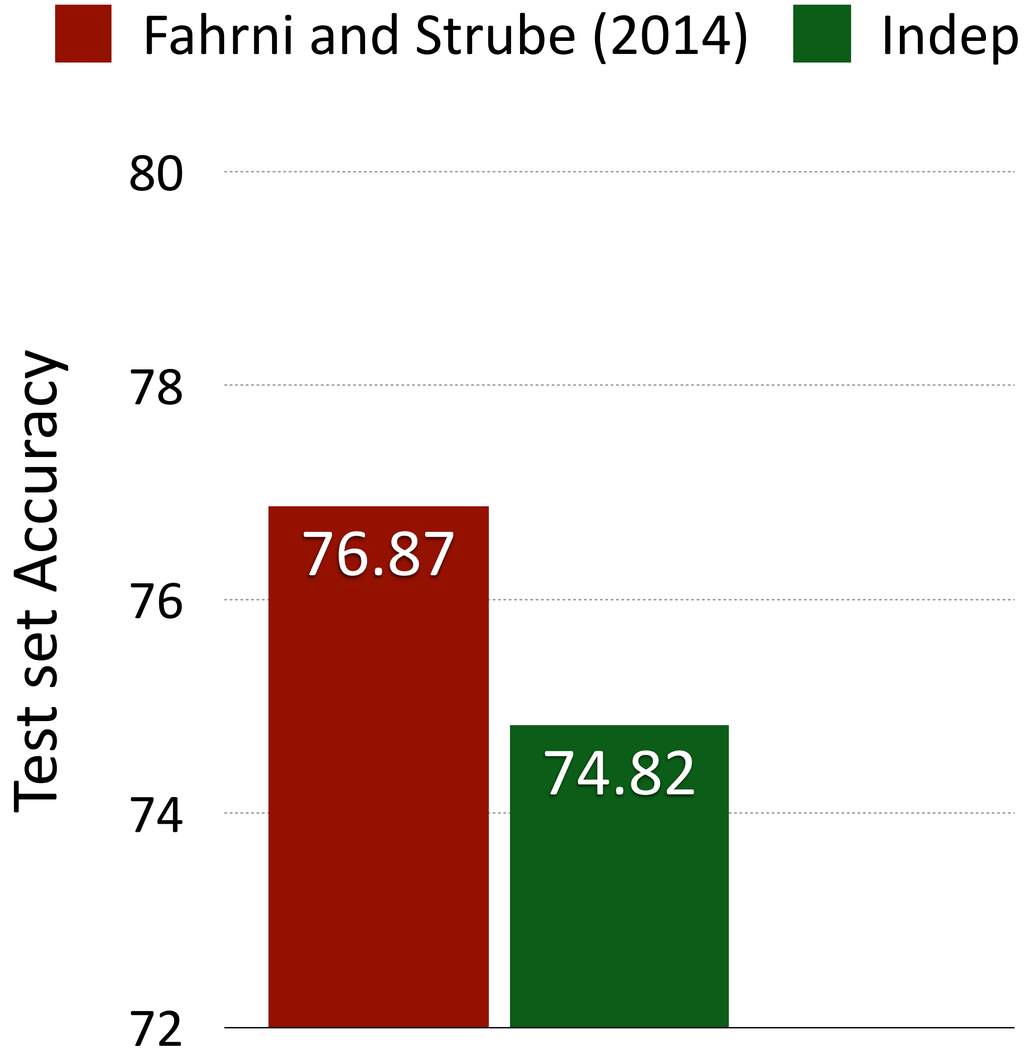

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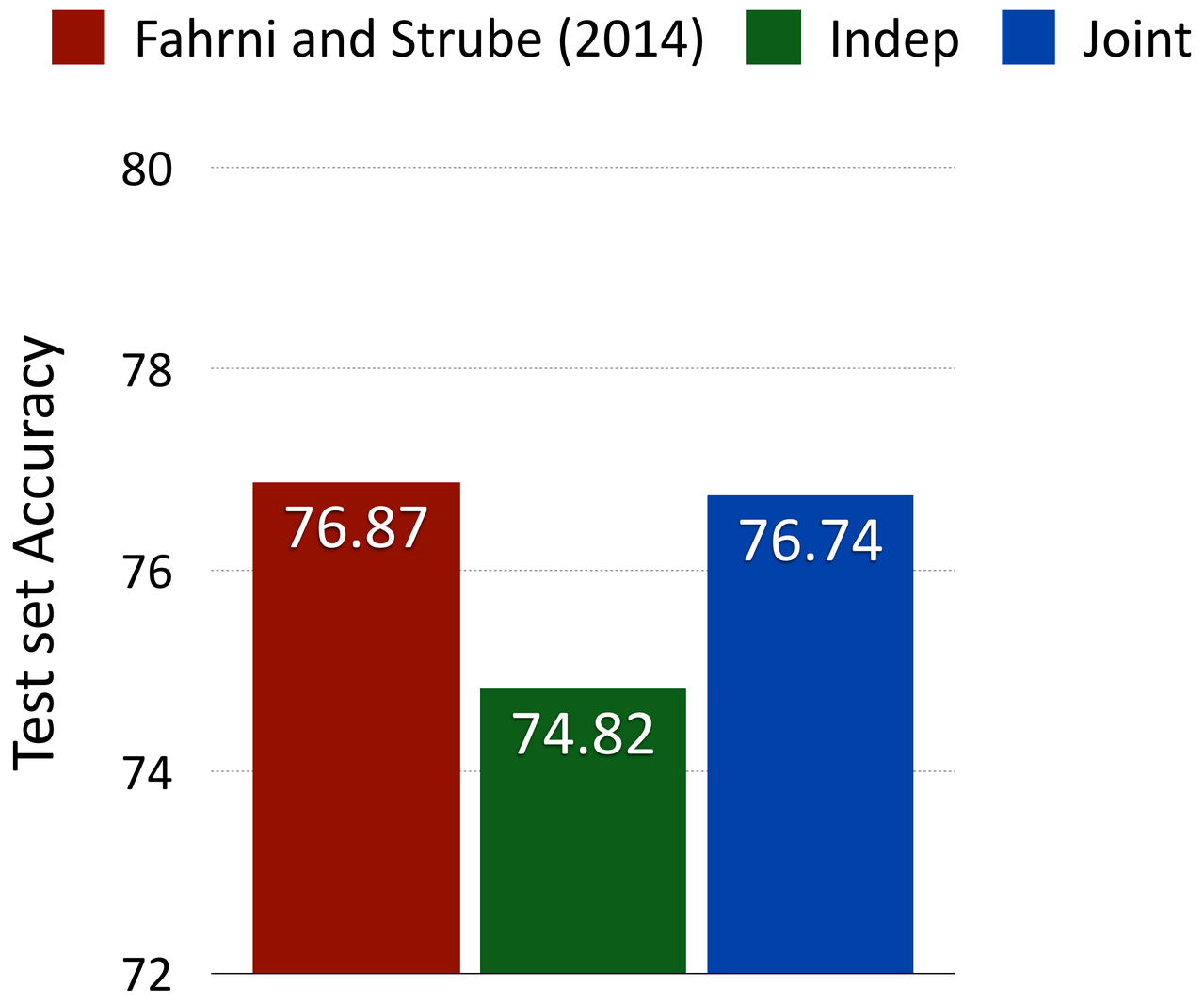
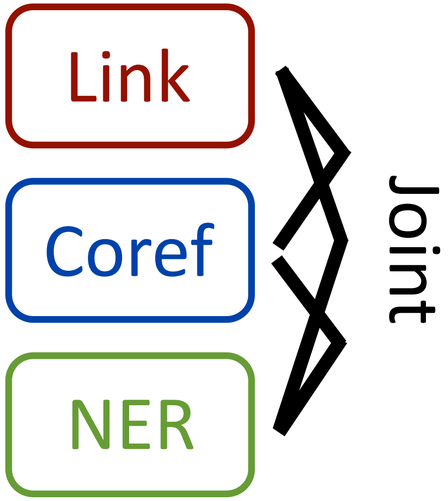
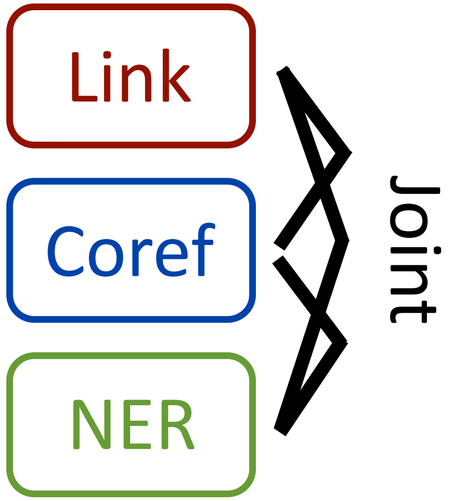


Modularity



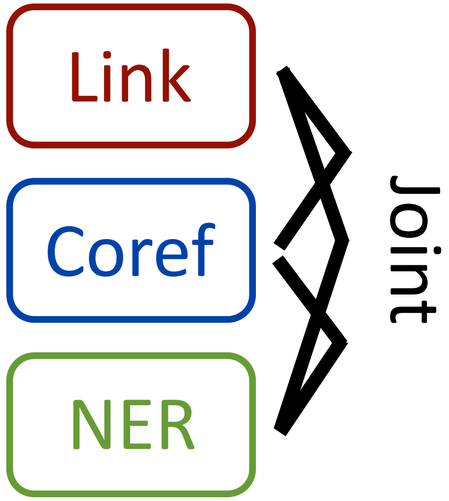
Modularity

- Component models are completely modularized, only need to expose marginals



Modularity

- Component models are completely modularized, only need to expose marginals
- Joint factors are also conceptually decoupled



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Thank you!

Ablations

	Coref	NER	Link
INDEP.	74.87	83.04	73.07
INDEP+LINKNER		+1.85	+2.41
INDEP+COREFNER	+0.56	+1.15	
INDEP+COREFLINK	+0.48		−0.16
JOINT−LINKNER	+0.79	+1.28	−0.06
JOINT−COREFNER	+0.56	+1.94	+2.07
JOINT−COREFLINK	+0.85	+2.68	+2.57
JOINT	+1.23	+2.90	+2.62

Chain-structured NER