Syntactic Theory

Typed Feature Structures (TFS)

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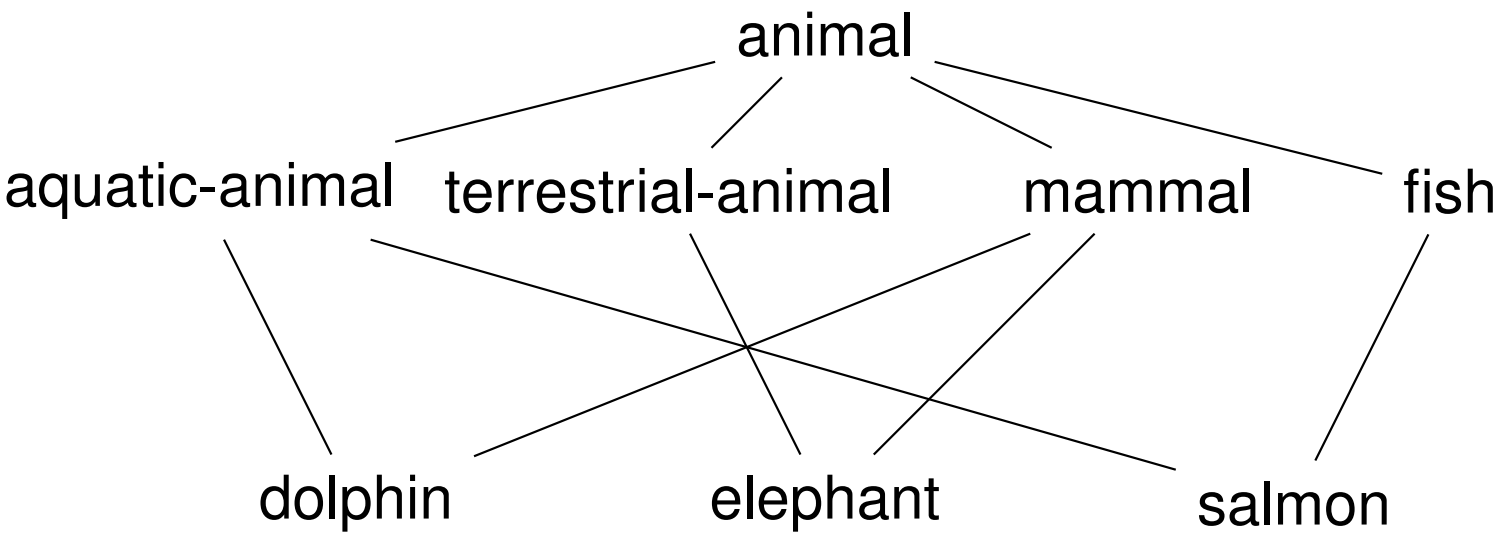
Type Hierarchy

Definition

A type hierarchy is a finite bounded complete partial order $\langle \textbf{Type}, \sqsubseteq \rangle$

- A type hierarchy describes a classification of feature structures (and the corresponding linguistic objects modeled by the feature structures)
- Multiple inheritance allows classification on multiple dimensions
- Types are occasionally referred to as **sorts**

Type Hierarchy: Example



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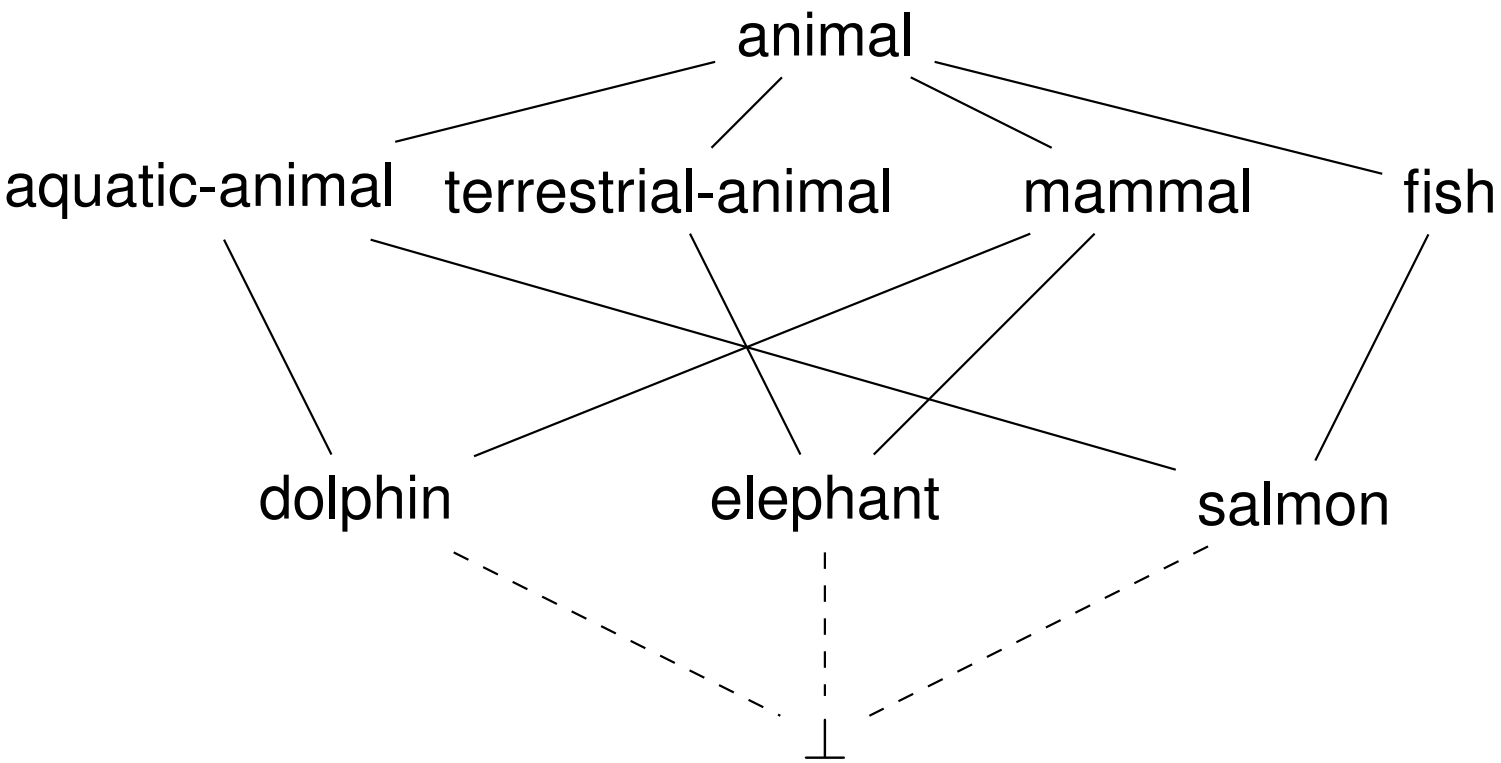
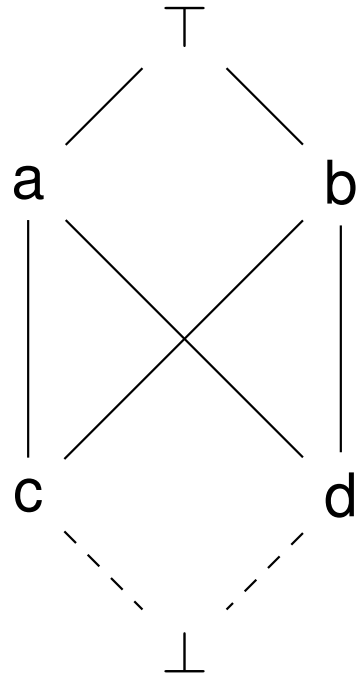


Type Hierarchy: Example (CPO $\Rightarrow$ BCPO)



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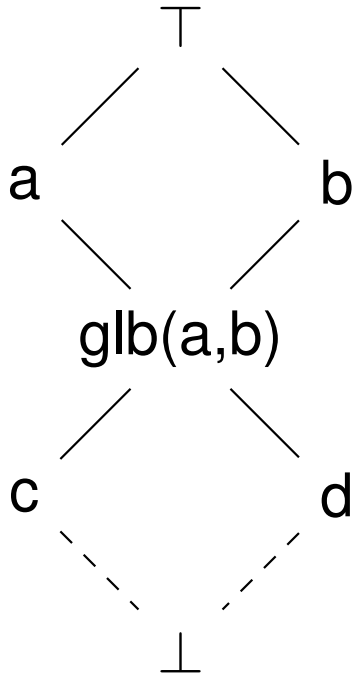


Type Subsumption

For two types $\sigma, \tau \in$ **Type**, if $\sigma \sqsubseteq \tau$, then

- σ **subsumes** τ
- σ is more **general** than τ; τ is more **specific** than σ
- σ is a **supertype** of τ; τ is a **subtype** of σ
- One unique type subsumes all other types: $*top*$ $\top$ []
- Types without any subtype (other than itself and $\bot$) are called **maximal types** or **leaf types**

- Subsumption relation is a partial order:
  - Reflexive: $\sigma \sqsubseteq \sigma$
  - Antisymmetric: if $\sigma \sqsubseteq \tau$ and $\tau \sqsubseteq \sigma$ then $\sigma = \tau$
  - Transitive: if $\sigma \sqsubseteq \omega$ and $\omega \sqsubseteq \tau$ then $\sigma \sqsubseteq \tau$

Typed Feature Structures

Definition

A typed feature structure is defined on a finite set of features **Feat** and a type hierarchy $\langle \mathbf{Type}, \sqsubseteq \rangle$ as a tuple $\langle Q, r, \delta, \theta \rangle$, where:

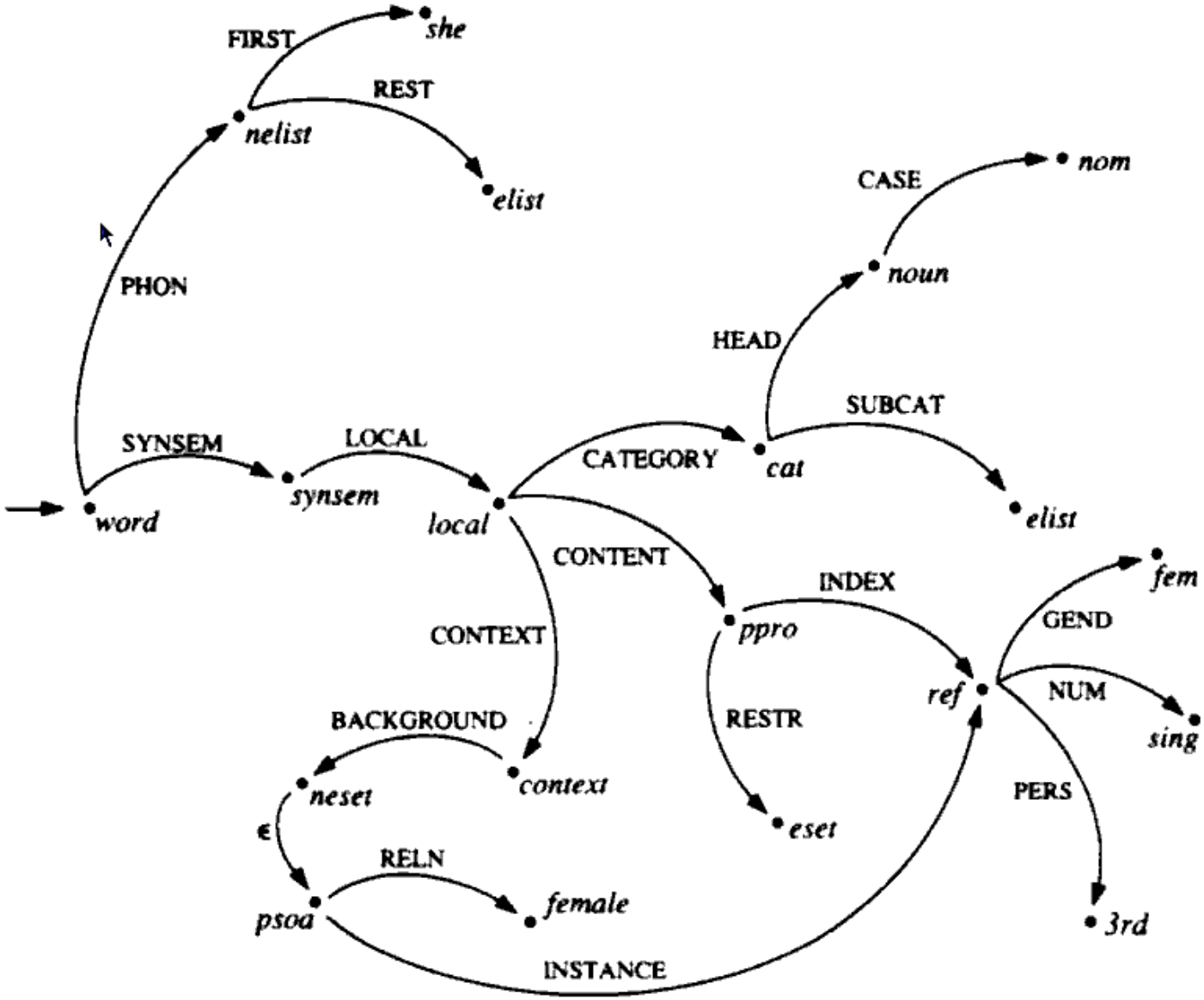
- Q is a finite set of nodes
- $r \in Q$ is the root node
- $\theta : Q \rightarrow \mathbf{Type}$ is a total typing function
- $\delta : Q \times \mathbf{Feat} \rightarrow Q$ is a partial feature value function

subject to the following conditions:

- r is not a $\delta-$descendant
- all members of Q except r are $\delta-$descendants of r

(*) there is no node n or path π such that $\delta(n, \pi) = n$ [non-cyclic]

Typed Feature Structures: An Example



Reentrancy

- A path is understood as a sequence of features: $\pi \in \textbf{Feat}^+$
- $\delta(n, \pi)$ is the value node starting from n following path π
- If $\delta(r, \pi) = \delta(r, \pi')$ and $\pi \neq \pi'$, i.e. two paths start from the root of the feature structure and point to the same node, then it is said there is a **reentrancy** between path π and π'
- Reentrancy is also called **token identity** or **path equivalence**

Token-Identity v.s. Type-Identity

There is another kind of identity: type identity

Definition

Two nodes n and n' are type-identical when

- $\theta(n) = \theta(n')$
- For any path π, the value of $\delta(n, \pi)$ is defined if and only if the value of $\delta(n', \pi)$ is defined, such that $\theta(\delta(n, \pi)) = \theta(\delta(n', \pi))$

- The identical values in type identity are specified independently; they are two values that happen to look the same
- Token-identical values are achieved by structure sharing, i.e. different paths are pointing to the same node in the TFS

Subsumption of Typed Feature Structures

Definition

F subsumes F', written $F \sqsubseteq F'$, if and only if

- $\pi \equiv_F \pi'$ implies $\pi \equiv_{F'} \pi'$
- $\mathcal{P}_F(\pi) = t$ implies $\mathcal{P}_{F'}(\pi) = t'$ and $t \sqsubseteq t'$

- $\pi \equiv_F \pi'$ means that feature structure F contains path equivalence or reentrancy between the path π and π', i.e. $\delta(r, \pi) = \delta(r, \pi')$ where r is the root node of F
- $\mathcal{P}_F(\pi) = \sigma$ means that the type on the path π in F is σ, in other words $\theta(\delta(r, \pi)) = \sigma$

Constraint Function

Types are associated with constraints expressed as typed feature structures

Definition

Constraint function $C : \langle \textbf{Type}, \sqsubseteq \rangle \rightarrow \mathcal{F}$ obeys the following conditions

- **Type** For a given type t, if $C(t)$ is the feature structure $\langle Q, q_0, \delta, \theta \rangle$ then $\theta(q_0) = t$
- **Monotonicity** Given type t_1 and t_2, if $t_1 \sqsubseteq t_2$ then $C(t_1) \sqsubseteq C(t_2)$
- **Compatibility of constraints** For all $q \in Q$ the feature structure $C(\theta(q)) \sqsubseteq F' = \langle Q', q, \delta, \theta \rangle$ and $\mathit{Feat}(q) = \mathit{Appfeat}(\theta(q))$
- **Maximal introduction of features** For every feature $f \in$ **Feat** there is a unique type t such that $f \in \mathit{Appfeat}(t)$ and there is no type s such that $s \sqsubset t$ and $f \in \mathit{Appfeat}(s)$

Appropriateness of Features

Definition

If $C(t) = \langle Q, q_0, \delta, \alpha \rangle$, then the appropriate features of t are defined as $Appfeat(t) = Feat(\langle F, q_0 \rangle)$ where $Feat(\langle F, q \rangle)$ is defined to be the set of features labeling transitions from the node q in some feature structure F i.e. $f \in Feat(\langle F, q \rangle)$ such that $\delta(f, q)$ is defined

Example

$$\begin{array}{rl} \textit{shirt} & \left[\begin{array}{ll} \text{NECK} & \text{length-measure} \end{array}\right] \\ \textit{trousers} & \left[\begin{array}{ll} \text{WAIST} & \text{length-measure} \end{array}\right] \end{array}$$

Well-formed Feature Structures

Definition

$F = \langle Q, q_0, \delta, \theta \rangle$ is a well-formed feature structure if and only if for all $q \in Q$, we have that $C(\theta(q)) \sqsubseteq F' = \langle Q', q, \delta, \theta \rangle$ and $Feat(\langle F, q \rangle) = Appfeat(\theta(q))$

Example

Typed feature structures described by the following AVMs are ill-formed

$$\textit{shirt}\begin{bmatrix}\text{NECK} & 65\text{kg}\end{bmatrix}$$

$$\textit{trousers}\begin{bmatrix}\text{NECK} & 50\text{cm}\end{bmatrix}$$

Signature

Definition

A signature consists of

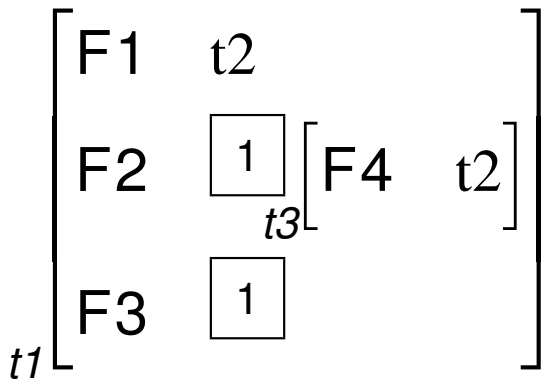
- A type inheritance hierarchy $\langle \textbf{Type}, \sqsubseteq \rangle$
- A corresponding constraint function $C : \langle \textbf{Type}, \sqsubseteq \rangle \rightarrow \mathcal{F}$

- Linguistic theories are developed by describing the inheritance type hierarchy together with proper constraints
- A constraint-based grammar framework

Attribute-Value Matrix (AVM)

Attribute-value matrix (AVM) notation is a **description language** to describe sets of feature structures, with the following three building blocks

- **Type** descriptions selects all objects of a particular type
- **Attribute-value pairs** describe objects that have a particular property. The attribute must be appropriate for the particular type, and the value can be any kind of description
- **Tags** to specify **token identity**



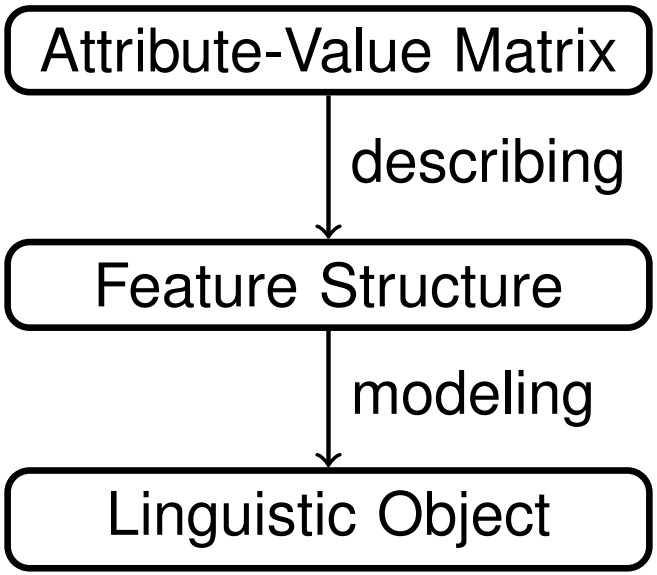
Attribute-Value Matrix (AVM) cont.

- Attribute-Value Matrix (AVM) is used to describe feature structures
- The order of the rows is not important
- Each attribute can only take one value, hence the following AVM is **improper** and does NOT describe any feature structure

$$\textit{person}\begin{bmatrix} \text{NAME} & \text{Sandy} \\ \text{AGE} & 29 \\ \text{AGE} & 30 \end{bmatrix}$$

- It is common practice to refer to AVMs as “feature structures”, although strictly speaking they are **feature structure descriptions**

Feature Structure v.s. Feature Structure Description



- Linguistic objects are modeled by feature structures, they are total with respect to the ontology declared in the signature. Technically, one say that these feature structures are
  - **Totally well-formed**: every node has all the attributes appropriate for its type and each attribute has an appropriate value
  - **Type-resolved**: every node is of a maximally specific type
- Each AVM can partially describe a set of feature structures by underspecifying information

Unification of Typed Feature Structures

Definition

The unification $F \sqcup F'$ of two feature structures F and F' is the greatest lower bound of F and F' in the collection of feature structures ordered by subsumption

Definition

The well-formed unification $F \sqcup_{wf} F'$ of two feature structures F and F' is the greatest lower bound of F and F' in the collection of well-formed feature structures ordered by subsumption

- Unification is the only operation used to process TFSes
- Grammars developed in such frameworks are called unification-based grammars

Unification of Typed Feature Structures (cont.)

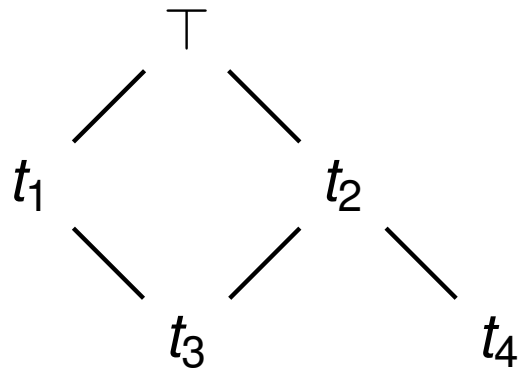
- A special symbol $\bot$ (bottom) is introduced to denote the failed unification of two incompatible feature structures
- Conceptually, $\forall \sigma \in \textbf{Type} \quad \sigma \sqsubseteq \bot$
- The type hierarchy (including $\bot$) is assumed to be a **bounded complete partial order (BCPO)**, so the unification operation is deterministic (glb exists for any pair of types)
- $\sigma \sqsubseteq \tau \Leftrightarrow \sigma \bigsqcup \tau = \tau$

Unification of AVMs

- As FSD, the unification of two AVMs A_1 A_2 results in a new AVM A_3 that describes the intersecting set of typed feature structures described by both AVMs A_1 A_2

Example

1. $$t_4\begin{bmatrix} F_1 & t_1 \end{bmatrix} \sqcup t_4\begin{bmatrix} F_1 & t_2 \\ F_2 & t_3 \end{bmatrix} =$$
2. $$t_4\begin{bmatrix} F_1 & t_1 \\ F_2 & t_2 \end{bmatrix} \sqcup \top\begin{bmatrix} F_1 & \boxed{1} \\ F_2 & \boxed{1} \end{bmatrix} =$$
3. $$\top\begin{bmatrix} F_1 & \boxed{1}\ t_1 \\ F_2 & \boxed{1} \end{bmatrix} \sqcup \top\begin{bmatrix} F_2 & \boxed{2} \\ F_3 & \boxed{2}\ t_4 \end{bmatrix} =$$



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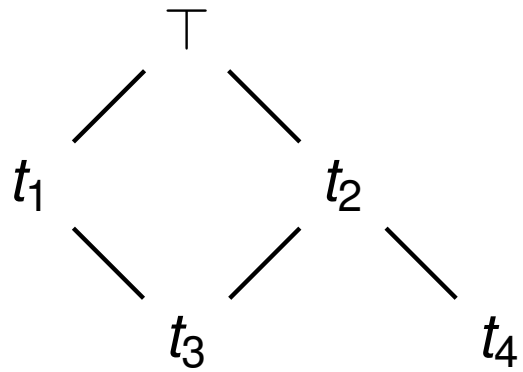

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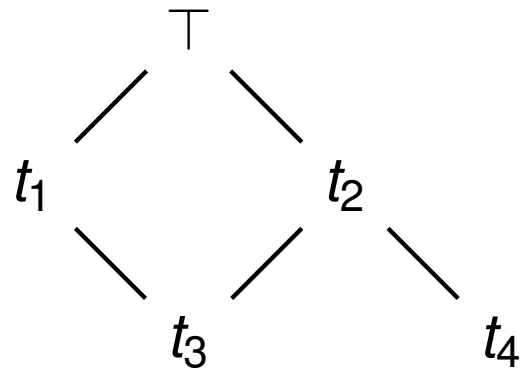

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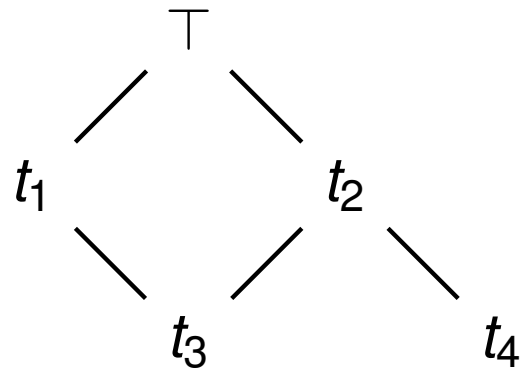
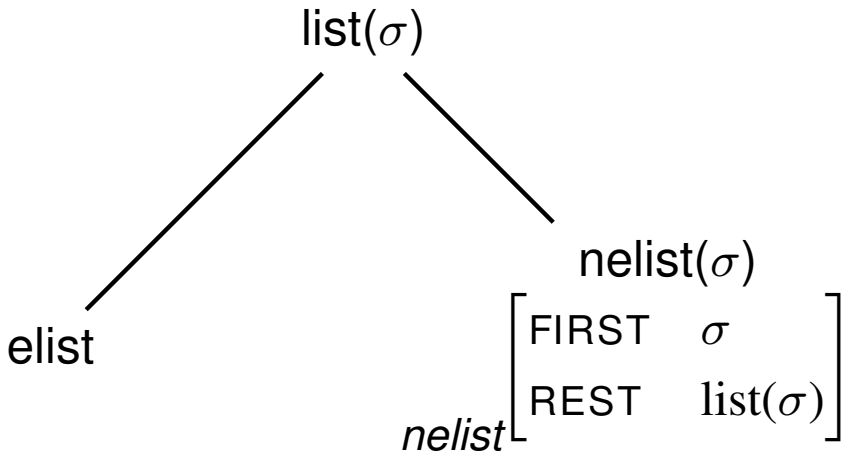
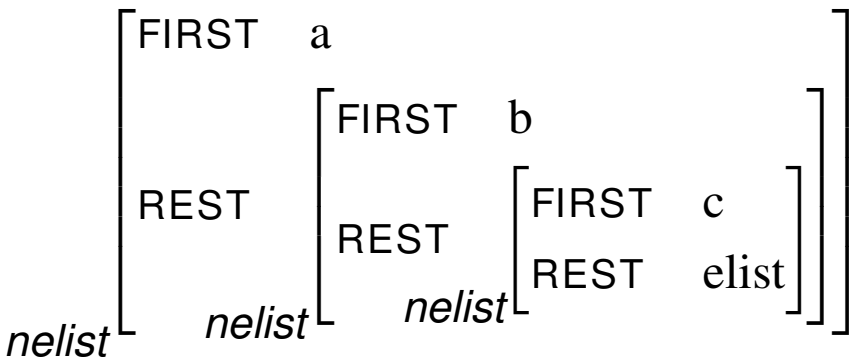


Lists in Typed Feature Structures

- Ordered list can be described using the following type hierarchy and constraints



- For convenience, we use notation $\langle$ A, B, C $\rangle$ to denote



Sets in Typed Feature Structures

- Type $set(\sigma)$ is used to describe **sets** of feature structures of type σ
- Notation $\{a, b, c\}$ is used to describe set membership
- Formally introducing **sets** in typed feature structures involves a fair amount of technical complications ([Carpenter, 1992])
- For our purpose, an intuitive understanding is sufficient
- In some implementations, lists are used to simulate sets

References I

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