TYPED FEATURE STRUCTURES AS DESCRIPTIONS

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ABSTRACT

A description is an entity that can be interpreted as true or false of an object, and using feature structures as descriptions accrues several computational benefits. In this paper, I create an explicit interpretation of a typed feature structure used as a description, define the notion of a satisfiable feature structure, and create a simple and effective algorithm to decide if a feature structure is satisfiable.

1. INTRODUCTION

Describing objects is one of several purposes for which linguists use feature structures. A description is an entity that can be interpreted as true or false of an object. For example, the conventional interpretation of the description ‘it is black’ is true of a soot particle, but false of a snowflake. Therefore, any use of a feature structure to describe an object demands that the feature structure can be interpreted as true or false of the object. In this paper, I tailor the semantics of [KING 1989] to suit the typed feature structures of [CARPENTER 1992], and so create an explicit interpretation of a typed feature structure used as a description. I then use this interpretation to define the notion of a satisfiable feature structure.

Though no feature structure algebra provides descriptions as expressive as those provided by a feature logic, using feature structures to describe objects profits from a large stock of available computational techniques to represent, test and process feature structures. In this paper, I demonstrate the computational benefits of marrying a tractable syntax and an explicit semantics by creating a simple and effective algorithm to decide the satisfiability

of a feature structure. Gerdemann and Götz’s Troll type resolution system implements both the semantics and an efficient refinement of the satisfiability algorithm I present here (see [GÖTZ 1993], [GERDEMANN AND KING 1994] and [GERDEMANN (FC)]).

2. A FEATURE STRUCTURE SEMANTICS

A signature provides the symbols from which to construct typed feature structures, and an interpretation gives those symbols meaning.

Definition 1. Σ is a signature iff

Σ is a sextuple $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$,

Ω is a set,

$\langle \mathcal{T}, \preceq \rangle$ is a partial order,

$\mathcal{S} = \left\{ \sigma \in \mathcal{T} \left| \begin{array}{l} \text{for each } \tau \in \mathcal{T}, \\ \text{if } \sigma \preceq \tau \text{ then } \sigma = \tau \end{array} \right. \right\}$,

$\mathcal{A}$ is a set,

$\mathfrak{F}$ is a partial function from the Cartesian product of $\mathcal{T}$ and $\mathcal{A}$ to $\mathcal{T}$, and

for each $\tau \in \mathcal{T}$, each $\tau' \in \mathcal{T}$ and each $\alpha \in \mathcal{A}$,
if $\mathfrak{F}(\tau, \alpha)$ is defined and $\tau \preceq \tau'$
then $\mathfrak{F}(\tau', \alpha)$ is defined, and
 $\mathfrak{F}(\tau, \alpha) \preceq \mathfrak{F}(\tau', \alpha)$.

Henceforth, I tacitly work with a signature $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$. I call members of Ω states, members of $\mathcal{T}$ types, $\preceq$ subsumption, members of $\mathcal{S}$ species, members of $\mathcal{A}$ attributes, and $\mathfrak{F}$ appropriateness.

Definition 2. I is an interpretation iff

I is a triple $\langle U, S, A \rangle$,

U is a set,

S is a total function from U to $\mathcal{S}$

A is a total function from $\mathcal{A}$ to the set of partial functions from U to U ,

for each $\alpha \in \mathcal{A}$ and each $u \in U$,

if $A(\alpha)(u)$ is defined

then $\mathfrak{F}(S(u), \alpha)$ is defined, and

$\mathfrak{F}(S(u), \alpha) \preceq S(A(\alpha)(u))$, and

for each $\alpha \in \mathcal{A}$ and each $u \in U$,

if $\mathfrak{F}(S(u), \alpha)$ is defined

then $A(\alpha)(u)$ is defined.

Suppose that I is an interpretation $\langle U, S, A \rangle$.

I call each member of U an object in I .

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Each type denotes a set of objects in I . The denotations of the species partition U , and S assigns each object in I the unique species whose denotation contains the object: object u is in the denotation of species σ iff $\sigma = S(u)$. Subsumption encodes a relationship between the denotations of species and types: object u is in the denotation of type τ iff $\tau \preceq S(u)$. So, if $\tau_1 \preceq \tau_2$ then the denotation of type τ_1 contains the denotation of type τ_2 .

Each attribute denotes a partial function from the objects in I to the objects in I , and A assigns each attribute the partial function it denotes. Appropriateness encodes a relationship between the denotations of species and attributes: if $\mathfrak{F}(\sigma, \alpha)$ is defined then the denotation of attribute α acts upon each object in the denotation of species σ to yield an object in the denotation of type $\mathfrak{F}(\sigma, \alpha)$, but if $\mathfrak{F}(\sigma, \alpha)$ is undefined then the denotation of attribute α acts upon no object in the denotation of species σ . So, if $\mathfrak{F}(\tau, \alpha)$ is defined then the denotation of attribute α acts upon each object in the denotation of type τ to yield an object in the denotation of type $\mathfrak{F}(\tau, \alpha)$.

I call a finite sequence of attributes a path, and write $\mathfrak{P}$ for the set of paths.

Definition 3. P is the path interpretation function under I iff

I is an interpretation $\langle U, S, A \rangle$,
 P is a total function from $\mathfrak{P}$ to the set of partial functions from U to U , and
for each $\langle \alpha_1, \dots, \alpha_n \rangle \in \mathfrak{P}$,
 $P\langle \alpha_1, \dots, \alpha_n \rangle$ is the functional composition of $A(\alpha_1), \dots, A(\alpha_n)$.

I write P_I for the path interpretation function under I .

Definition 4. F is a feature structure iff

F is a quadruple $\langle Q, q, \delta, \theta \rangle$,
 Q is a finite subset of Ω ,
 $q \in Q$,
 δ is a finite partial function from the Cartesian product of Q and $\mathfrak{A}$ to Q ,
 θ is a total function from Q to $\mathfrak{T}$, and
for each $q' \in Q$,
for some $\pi \in \mathfrak{P}$, π runs to q' in F ,
where $\langle \alpha_1, \dots, \alpha_n \rangle$ runs to q' in F iff
 $\langle \alpha_1, \dots, \alpha_n \rangle \in \mathfrak{P}$,
 $q' \in Q$, and
for some $\{q_0, \dots, q_n\} \subseteq Q$,
 $q = q_0$,
for each $i < n$,
 $\delta(q_i, \alpha_{i+1})$ is defined, and
 $\delta(q_i, \alpha_{i+1}) = q_{i+1}$, and
 $q_n = q'$.

Each feature structure is a connected Moore

machine (see [MOORE 1956]) with finitely many states, input alphabet $\mathfrak{A}$, and output alphabet $\mathfrak{T}$.

Definition 5. F is true of u under I iff

F is a feature structure $\langle Q, q, \delta, \theta \rangle$,
 I is an interpretation $\langle U, S, A \rangle$,
 u is an object in I , and
for each $\pi_1 \in \mathfrak{P}$, each $\pi_2 \in \mathfrak{P}$ and each $q' \in Q$,
if π_1 runs to q' in F , and
 π_2 runs to q' in F
then $P_I(\pi_1)(u)$ is defined,
 $P_I(\pi_2)(u)$ is defined,
 $P_I(\pi_1)(u) = P_I(\pi_2)(u)$, and
 $\theta(q') \preceq S(P_I(\pi_1)(u))$.

Definition 6. F is a satisfiable feature structure iff

F is a feature structure, and
for some interpretation I and some object u in I , F is true of u under I .

3. MORPHS

The abundance of interpretations seems to preclude an effective algorithm to decide if a feature structure is satisfiable. However, I insert *morphs* between feature structures and objects to yield an interpretation free characterisation of a satisfiable feature structure.

Definition 7. M is a semi-morph iff

M is a triple $\langle \Delta, \Gamma, \Lambda \rangle$,
 Δ is a nonempty subset of $\mathfrak{P}$,
 Γ is an equivalence relation over Δ ,
for each $\alpha \in \mathfrak{A}$, each $\pi_1 \in \mathfrak{P}$ and each $\pi_2 \in \mathfrak{P}$,
if $\pi_1 \alpha \in \Delta$ and $\langle \pi_1, \pi_2 \rangle \in \Gamma$
then $\langle \pi_1 \alpha, \pi_2 \alpha \rangle \in \Gamma$,
 Λ is a total function from Δ to $\mathfrak{S}$,
for each $\pi_1 \in \mathfrak{P}$ and each $\pi_2 \in \mathfrak{P}$,
if $\langle \pi_1, \pi_2 \rangle \in \Gamma$ then $\Lambda(\pi_1) = \Lambda(\pi_2)$, and
for each $\alpha \in \mathfrak{A}$ and each $\pi \in \mathfrak{P}$,
if $\pi \alpha \in \Delta$
then $\pi \in \Delta$, $\mathfrak{F}(\Lambda(\pi), \alpha)$ is defined, and
 $\mathfrak{F}(\Lambda(\pi), \alpha) \preceq \Lambda(\pi \alpha)$.

Definition 8. M is a morph iff

M is a semi-morph $\langle \Delta, \Gamma, \Lambda \rangle$, and
for each $\alpha \in \mathfrak{A}$ and each $\pi \in \mathfrak{P}$,
if $\pi \in \Delta$ and $\mathfrak{F}(\Lambda(\pi), \alpha)$ is defined
then $\pi \alpha \in \Delta$.

Each morph is the Moshier abstraction (see [MOSHIER 1988]) of a connected and totally well-typed (see [CARPENTER 1992]) Moore machine with possibly infinitely many states, input alphabet $\mathfrak{A}$, and output alphabet $\mathfrak{S}$.

Definition 9. M abstracts u under I iff

M is a morph $\langle \Delta, \Gamma, \Lambda \rangle$,
 I is an interpretation $\langle U, S, A \rangle$,
 u is an object in I ,
for each $\pi_1 \in \mathfrak{P}$ and each $\pi_2 \in \mathfrak{P}$,
 $\langle \pi_1, \pi_2 \rangle \in \Gamma$
iff $P_I(\pi_1)(u)$ is defined,
 $P_I(\pi_2)(u)$ is defined, and
 $P_I(\pi_1)(u) = P_I(\pi_2)(u)$, and
for each $\sigma \in \mathfrak{S}$ and each $\pi \in \mathfrak{P}$,
 $\langle \pi, \sigma \rangle \in \Lambda$
iff $P_I(\pi)(u)$ is defined, and
 $\sigma = S(P_I(\pi)(u))$.

Proposition 10. For each interpretation I and each object u in I ,

some unique morph abstracts u under I .

I thus write of the abstraction of u under I .

Definition 11. u is a standard object iff

u is a quadruple $\langle \Delta, \Gamma, \Lambda, E \rangle$,
 $\langle \Delta, \Gamma, \Lambda \rangle$ is a morph, and
 E is an equivalence class under Γ .

I write $\tilde{U}$ for the set of standard objects, write

$\tilde{S}$ for the total function from $\tilde{U}$ to $\mathfrak{S}$, where

for each $\sigma \in \mathfrak{S}$ and each $\langle \Delta, \Gamma, \Lambda, E \rangle \in \tilde{U}$,
 $\tilde{S}(\langle \Delta, \Gamma, \Lambda, E \rangle) = \sigma$
iff for some $\pi \in E$, $\Lambda(\pi) = \sigma$,

and write $\tilde{A}$ for the total function from $\mathfrak{A}$ to the set of partial functions from $\tilde{U}$ to $\tilde{U}$, where

for each $\alpha \in \mathfrak{A}$, each $\langle \Delta, \Gamma, \Lambda, E \rangle \in \tilde{U}$ and
each $\langle \Delta', \Gamma', \Lambda', E' \rangle \in \tilde{U}$,
 $\tilde{A}(\alpha)(\langle \Delta, \Gamma, \Lambda, E \rangle)$ is defined, and
 $\tilde{A}(\alpha)(\langle \Delta, \Gamma, \Lambda, E \rangle) = \langle \Delta', \Gamma', \Lambda', E' \rangle$
iff $\langle \Delta, \Gamma, \Lambda \rangle = \langle \Delta', \Gamma', \Lambda' \rangle$, and
for some $\pi \in E$, $\pi\alpha \in E'$.

Lemma 12. $\langle \tilde{U}, \tilde{S}, \tilde{A} \rangle$ is an interpretation.

I write $\tilde{I}$ for $\langle \tilde{U}, \tilde{S}, \tilde{A} \rangle$.

Lemma 13. For each $\langle \Delta, \Gamma, \Lambda, E \rangle \in \tilde{U}$, each
 $\langle \Delta', \Gamma', \Lambda', E' \rangle \in \tilde{U}$ and each $\pi \in \mathfrak{P}$,

$P_{\tilde{I}}(\pi)(\langle \Delta, \Gamma, \Lambda, E \rangle)$ is defined, and
 $P_{\tilde{I}}(\pi)(\langle \Delta, \Gamma, \Lambda, E \rangle) = \langle \Delta', \Gamma', \Lambda', E' \rangle$
iff $\langle \Delta, \Gamma, \Lambda \rangle = \langle \Delta', \Gamma', \Lambda' \rangle$, and
for some $\pi' \in E$, $\pi'\pi \in E'$.

Proof. By induction on the length of π . ■

Lemma 14. For each $\langle \Delta, \Gamma, \Lambda, E \rangle \in \tilde{U}$,

if E is the equivalence class of the empty
path under Γ

then the abstraction of $\langle \Delta, \Gamma, \Lambda, E \rangle$ under $\tilde{I}$
is $\langle \Delta, \Gamma, \Lambda \rangle$.

Proposition 15. For each morph M ,

for some interpretation I and some object u
in I ,

M is the abstraction of u under I .

Definition 16. F approximates M iff

F is a feature structure $\langle Q, q, \delta, \theta \rangle$,
 M is a morph $\langle \Delta, \Gamma, \Lambda \rangle$, and
for each $\pi_1 \in \mathfrak{P}$, each $\pi_2 \in \mathfrak{P}$ and each
 $q' \in Q$,
if π_1 runs to q' in F , and
 π_2 runs to q' in F
then $\langle \pi_1, \pi_2 \rangle \in \Gamma$, and
 $\theta(q') \preceq \Lambda(\pi_1)$.

A feature structure approximates a morph iff the Moshier abstraction of the feature structure abstractly subsumes (see [CARPENTER 1992]) the morph.

Proposition 17. For each interpretation I , each object u in I and each feature structure F ,

F is true of u under I

iff F approximates the abstraction of u
under I .

Theorem 18. For each feature structure F ,

F is satisfiable iff F approximates some
morph.

Proof. From propositions 15 and 17. ■

4. RESOLVED FEATURE STRUCTURES

Though theorem 18 gives an interpretation free characterisation of a satisfiable feature structure, the characterisation still seems to admit of no effective algorithm to decide if a feature structure is satisfiable. However, I use theorem 18 and *resolved feature structures* to yield a less general interpretation free characterisation of a satisfiable feature structure that admits of such an algorithm.

Definition 19. R is a resolved feature structure iff

R is a feature structure $\langle Q, q, \delta, \rho \rangle$,
 ρ is a total function from Q to $\mathfrak{S}$, and
for each $\alpha \in \mathfrak{A}$ and each $q' \in Q$,
if $\delta(q', \alpha)$ is defined
then $\mathfrak{F}(\rho(q'), \alpha)$ is defined, and
 $\mathfrak{F}(\rho(q'), \alpha) \preceq \rho(\delta(q', \alpha))$.

Each resolved feature structure is a well-typed (see [CARPENTER 1992]) feature structure with output alphabet $\mathfrak{S}$.

Definition 20. R is a resolvent of F iff

R is a resolved feature structure $\langle Q, q, \delta, \rho \rangle$,
 F is a feature structure $\langle Q, q, \delta, \theta \rangle$, and
for each $q' \in Q$, $\theta(q') \preceq \rho(q')$.

Proposition 21. For each interpretation I , each object u in I and each feature structure F ,

F is true of u under I

iff some resolvent of F is true of u under I .

Definition 22. $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$ is rational iff for each $\sigma \in \mathcal{S}$ and each $\alpha \in \mathcal{A}$,

if $\mathfrak{F}(\sigma, \alpha)$ is defined

then for some $\sigma' \in \mathcal{S}$, $\mathfrak{F}(\sigma, \alpha) \preceq \sigma'$.

Proposition 23. If $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$ is rational then for each resolved feature structure R , R is satisfiable.

Proof. Suppose that $R = \langle Q, q, \delta, \rho \rangle$ and β is a bijection from ordinal ζ to $\mathcal{S}$. Let

$$\Delta_0 = \left\{ \pi \left| \begin{array}{l} \text{for some } q' \in Q, \\ \pi \text{ runs to } q' \text{ in } R \end{array} \right. \right\},$$

$$\Gamma_0 = \left\{ \langle \pi_1, \pi_2 \rangle \left| \begin{array}{l} \text{for some } q' \in Q, \\ \pi_1 \text{ runs to } q' \text{ in } R, \text{ and} \\ \pi_2 \text{ runs to } q' \text{ in } R \end{array} \right. \right\},$$

and

$$\Lambda_0 = \left\{ \langle \pi, \sigma \rangle \left| \begin{array}{l} \text{for some } q' \in Q, \\ \pi \text{ runs to } q' \text{ in } R, \text{ and} \\ \sigma = \rho(q') \end{array} \right. \right\}.$$

For each $n \in \mathbb{N}$, let

$$\Delta_{n+1} = \left\{ \pi \alpha \left| \begin{array}{l} \alpha \in \mathcal{A}, \\ \pi \in \Delta_n, \text{ and} \\ \mathfrak{F}(\Lambda_n(\pi), \alpha) \text{ is defined} \end{array} \right. \right\},$$

$$\Gamma_{n+1} = \left\{ \langle \pi_1 \alpha, \pi_2 \alpha \rangle \left| \begin{array}{l} \alpha \in \mathcal{A}, \\ \pi_1 \alpha \in \Delta_{n+1}, \\ \pi_2 \alpha \in \Delta_{n+1}, \text{ and} \\ \langle \pi_1, \pi_2 \rangle \in \Gamma_n, \end{array} \right. \right\}, \text{ and}$$

$$\Lambda_{n+1} = \left\{ \langle \pi \alpha, \beta(\xi) \rangle \left| \begin{array}{l} \alpha \in \mathcal{A}, \\ \pi \in \Delta_n, \\ \pi \alpha \in \Delta_{n+1} \setminus \Delta_n, \text{ and} \\ \xi \text{ is the least ordinal} \\ \text{in } \zeta \text{ such that} \\ \mathfrak{F}(\Lambda_n(\pi), \alpha) \preceq \beta(\xi) \end{array} \right. \right\}.$$

For each $n \in \mathbb{N}$, $\langle \Delta_n, \Gamma_n, \Lambda_n \rangle$ is a semi-morph. Let

$$\Delta = \bigcup \{ \Delta_n \mid n \in \mathbb{N} \},$$

$$\Gamma = \bigcup \{ \Gamma_n \mid n \in \mathbb{N} \}, \text{ and}$$

$$\Lambda = \bigcup \{ \Lambda_n \mid n \in \mathbb{N} \}.$$

$\langle \Delta, \Gamma, \Lambda \rangle$ is a morph that R approximates. By theorem 18, R is satisfiable. ■

Theorem 24. If $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$ is rational then for each feature structure F ,

F is satisfiable iff F has a resolvent.

Proof. From propositions 21 and 23. ■

5. A SATISFIABILITY ALGORITHM

In this section, I use theorem 24 to show how – given a rational signature that meets reasonable computational conditions – to construct an effective algorithm to decide if a feature structure is satisfiable.

Definition 25. $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$ is computable iff

Ω , $\mathcal{T}$ and $\mathcal{A}$ are countable,

$\mathcal{S}$ is finite,

for some effective function SUB,

for each $\tau_1 \in \mathcal{T}$ and each $\tau_2 \in \mathcal{T}$,

if $\tau_1 \preceq \tau_2$

then $\text{SUB}(\tau_1, \tau_2) = \text{'true'}$

otherwise $\text{SUB}(\tau_1, \tau_2) = \text{'false'}$, and

for some effective function APP,

for each $\tau \in \mathcal{T}$ and each $\alpha \in \mathcal{A}$,

if $\mathfrak{F}(\tau, \alpha)$ is defined

then $\text{APP}(\tau, \alpha) = \mathfrak{F}(\tau, \alpha)$

otherwise $\text{APP}(\tau, \alpha) = \text{'undefined'}$.

Proposition 26. If $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$ is computable then for some effective function RES,

for each feature structure F ,

$\text{RES}(F)$ is a list of the resolvents of F .

Proof. Since $\langle \Omega, \mathcal{T}, \preceq, \mathcal{S}, \mathcal{A}, \mathfrak{F} \rangle$ is computable, for some effective function GEN,

for each finite $Q \subseteq \Omega$,

$\text{GEN}(Q)$ is a list of the total functions

from Q to $\mathcal{S}$,

for some effective function TEST₁,

for each finite set Q , each finite partial

function δ from the Cartesian product of Q

and $\mathcal{A}$ to Q , and each total function θ from

Q to $\mathcal{T}$,

if for each $\langle q, \alpha \rangle$ in the domain of δ ,

$\mathfrak{F}(\theta(q), \alpha)$ is defined, and

$\mathfrak{F}(\theta(q), \alpha) \preceq \delta(q, \alpha)$

then $\text{TEST}_1(\delta, \theta) = \text{'true'}$

otherwise $\text{TEST}_1(\delta, \theta) = \text{'false'}$,

and for some effective function TEST₂,

for each finite set Q , each total function θ_1

from Q to $\mathcal{T}$ and each total function θ_2

from Q to $\mathcal{T}$,

if for each $q \in Q$, $\theta_1(q) \preceq \theta_2(q)$

then $\text{TEST}_2(\theta_1, \theta_2) = \text{'true'}$

otherwise $\text{TEST}_2(\theta_1, \theta_2) = \text{'false'}$.

Construct RES as follows:

for each feature structure $\langle Q, q, \delta, \theta \rangle$,

set $\Sigma_{\text{in}} = \text{GEN}(Q)$ and $\Sigma_{\text{out}} = \langle \rangle$

while $\Sigma_{\text{in}} = \langle \rho, \rho_1, \dots, \rho_i \rangle$ is not empty

do set $\Sigma_{\text{in}} = \langle \rho_1, \dots, \rho_i \rangle$

if $\text{TEST}_1(\delta, \rho) = \text{'true'}$,

$\text{TEST}_2(\theta, \rho) = \text{'true'}$, and

$\Sigma_{\text{out}} = \langle \rho'_1, \dots, \rho'_j \rangle$

then set $\Sigma_{\text{out}} = \langle \rho, \rho'_1, \dots, \rho'_j \rangle$

if $\Sigma_{\text{out}} = \langle \rho_1, \dots, \rho_n \rangle$

then output $\langle \langle Q, q, \delta, \rho_1 \rangle, \dots, \langle Q, q, \delta, \rho_n \rangle \rangle$.

RES is an effective algorithm, and

for each feature structure F ,

$\text{RES}(F)$ is a list of the resolvents of F .

■

Theorem 27. *If $\langle \Omega, \mathcal{F}, \preceq, \mathcal{G}, \mathcal{A}, \mathcal{F} \rangle$ is rational and computable then for some effective function SAT,*

for each feature structure F ,
if F is satisfiable
then $\text{SAT}(F) = \text{'true'}$
otherwise $\text{SAT}(F) = \text{'false'}$.

Proof. From theorem 24 and proposition 26.

■
 Gerdemann and Götz's Troll system (see [GÖTZ 1993], [GERDEMANN AND KING 1994] and [GERDEMANN (FC)]) employs an efficient refinement of RES to test the satisfiability of feature structures. In fact, Troll represents each feature structure as a disjunction of the resolvants of the feature structure. Loosely speaking, the resolvants of a feature structure have the same underlying finite state automaton as the feature structure, and differ only in their output function. Troll exploits this property to represent each feature structure as a finite state automaton and a set of output functions. The Troll unifier is closed on these representations. Thus, though RES is computationally expensive, Troll uses RES only during compilation, never during run time.

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