

The Signature of Semantic Structures

D. Gueorguiev 10/2/2021

Let us have the compound particle V_{comp} represented by its elementary particle sequence and semantic tree $stree(V_{comp})$:

$$stree(V_{comp}) =$$

```

      /  \  /  \
     /    \ /    \
    /      \ /      \
   /        \ /        \
  /          \ /          \
 V1          V2          V3
 /  \      /  \      /  \
V4 V5 V6 V7 V8 V9

```

The property tree for each V -particle $V_k, k = 1..9$ are given with the algebraic notation discussed in [Semantic Tree Operations](#).

$ptree(V_k) = \sum_{k \in \mathfrak{T}(V_k), i \in \mathbb{P}(V_k)} (k, P_i)$. Here k denotes the path $(k_{l_1}, k_{l_2}, \dots, k_{l_h})$ constructed by branching consecutively along the k_{l_1} -th branch from the top level, then the k_{l_2} -th branch from the lower level and finally k_{l_h} -th branch from the h -th level. The set $\mathfrak{T}(V_k)$ denotes the set of all paths from the root to a leaf in the property tree of V_k . The set $\mathbb{P}(V_k)$ denotes the indices of the vertices in the property tree of V_k .

$$\begin{array}{ccc}
 V_1 & V_2 & \dots & V_9 \\
 \begin{array}{c}
 P_1 \ P_2 \ P_3 \\
 \backslash \ | \ / \ \dots \\
 P_k \ \dots \ o \ \dots P_i \\
 \dots \ / \ | \ \backslash \ \dots \\
 P_{j+1} \ P_j \ P_{j-1}
 \end{array} &
 \begin{array}{c}
 P_1 \ \dots \ o \ \dots P_2 \\
 / \ | \ \backslash \\
 P_3 \ P_4 \ P_5 \ \dots \\
 / \ \backslash \ \quad | \ \backslash \\
 P_6 \ P_7 \ \quad P_8 \ P_9 \\
 | \\
 P_{10}
 \end{array} &
 \begin{array}{c}
 P_1 \ \dots \ o \ \dots P_2
 \end{array}
 \end{array}$$

Expressing the property tree of V_1 with the algebraic notation discussed earlier:

$$ptree(V_1) = \sum_{k_j \in \mathfrak{T}(V_1), i \in \mathbb{P}(V_1)} (k_j, P_i)$$

Similarly, $ptree(V_2)$ is given with

$$\begin{aligned}
 ptree(V_2) = & (1, P_0) + (k_1, P_1) + (k_2, P_2) + (k_3, P_3) + (k_4, P_4) + (k_5, P_5) + (k_3 k_1, P_6) + (k_3 k_2, P_7) \\
 & + (k_5 k_1, P_8) + (k_5 k_2, P_9) + (k_3 k_1 k_1, P_{10})
 \end{aligned}$$

Here P_0 is $text(V_2)$.

Now if we expand the property trees for each V -particle in the semantic tree for the composite particle V_{comp} we will have a larger augmented property tree. This augmented property tree represents the semantic structure of V_{comp} and can be recorded in a matrix form which is the semantic signature of V_{comp} . The semantic signature matrix of V_{comp} will have the following structure:

$$ssig(V_{comp}) = [p_0 \ a_{0,1} \ p_1 \ p_0 \ a_{0,2} \ p_2 \ p_0 \ a_{0,3} \ p_3 \ \dots \ p_p \ a_{p,q} \ p_q]$$

The last matrix can be rewritten in block matrix notation:

$$ssig(V_{comp}) = [\mathbf{B}_1 \ \mathbf{B}_2 \ \mathbf{B}_3 \ \dots \ \mathbf{B}_q]$$

$$\mathbf{B}_1 = [\mathbf{p}_0 \ \mathbf{a}_{0,1} \ \mathbf{p}_1], \mathbf{B}_2 = [\mathbf{p}_0 \ \mathbf{a}_{0,2} \ \mathbf{p}_2], \mathbf{B}_3 = [\mathbf{p}_0 \ \mathbf{a}_{0,3} \ \mathbf{p}_3], \dots, \mathbf{B}_q = [\mathbf{p}_p \ \mathbf{a}_{p,q} \ \mathbf{p}_q]$$

Here the block matrix \mathbf{B}_1 fully describes the property P_1 including how it is connected to the property tree $ptree(V_1)$. Similarly, \mathbf{B}_2 and \mathbf{B}_3 fully describes the properties P_2 and P_3 and their connectivity to $ptree(V_1)$. Finally, \mathbf{B}_q fully describes the property P_q and its connectivity to $ptree(V_9)$. From now on we will denote the block matrices \mathbf{B}_i as *semantic elements* of V_{comp} .

Statement: Every semantic particle, primitive or composite, can be represented as a sequence of *semantic elements*.

Definition: Semantic distance between two semantic elements B_1 and B_2

The semantic element B_1 represents two properties - P_i and P_j connected through association link $A_{i,j}$. The properties P_i and P_j are represented by their property signatures \mathbf{p}_i and \mathbf{p}_j . The association link $A_{i,j}$ is represented with its association matrix $\mathbf{a}_{i,j}$ and semantic significance vector $\mathbf{w}_{i,j}$. (Note: Sometimes for clarity all vectors in a block matrix representing semantic element will be denoted with the vector symbol $\vec{}$ when clear distinction needs to be made). For details refer to the document [Note On Binding of Association Property to Semantic Properties](#). Similarly the semantic element B_2 represents the properties P_k and P_l connected through association link $A_{k,l}$. As before the properties P_k and P_l are represented by their property signatures \mathbf{p}_k and \mathbf{p}_l . The association link $A_{k,l}$ is represented with its association matrix $\mathbf{a}_{k,l}$ and semantic significance vector $\mathbf{w}_{k,l}$.

Let \mathbf{B}_1 denotes the matrix of the first semantic element B_1 given with $\mathbf{B}_1 = [\mathbf{p}_i \ \mathbf{a}_{i,j} \ \mathbf{p}_j]$

Let \mathbf{B}_2 denotes the matrix of the second semantic element B_2 given with $\mathbf{B}_2 = [\mathbf{p}_k \ \mathbf{a}_{k,l} \ \mathbf{p}_l]$

Then the semantic distance between the two is given with:

$$sdist(B_1, B_2) = sdist(P_i, P_k) + sdist(A_{i,j}, A_{k,l}) + sdist(P_j, P_l)$$

where

$$sdist(P_i, P_k) = |\mathbf{p}_i - \mathbf{p}_k|, \quad sdist(P_j, P_l) = |\mathbf{p}_j - \mathbf{p}_l|$$

$$sdist(A_{i,j}, A_{k,l}) = |\mathbf{w}_{i,j} - \mathbf{w}_{k,l}| \times sdist(\mathbf{a}_{i,j}, \mathbf{a}_{k,l})$$

Definition: The semantic distance of two semantic matrices \mathbf{a} and \mathbf{b} which have the same number of columns is given with:

$$sdist(\mathbf{a}, \mathbf{b}) = \sum_{i=1}^n |\vec{\mathbf{a}}_i - \vec{\mathbf{b}}_i| \text{ where } \mathbf{a} = [\vec{\mathbf{a}}_1 \ \vec{\mathbf{a}}_2 \ \dots \ \vec{\mathbf{a}}_n] \text{ and } \mathbf{b} = [\vec{\mathbf{b}}_1 \ \vec{\mathbf{b}}_2 \ \dots \ \vec{\mathbf{b}}_n].$$

In the block matrix for $ssig(V_{comp})$ \mathbf{p}_0 denotes the signature column vector of the property P_0 , $\mathbf{a}_{0,1}$ denotes the association matrix of the arc between property P_0 and property P_1 , $\mathbf{a}_{p,q}$ denotes the association matrix of the arc between property P_p and P_q . Let us denote the number of rows of $ssig(V_{comp})$ by N and the number of columns by M .

The semantic signature matrix $ssig(V_{comp})$ can be decomposed as a sum of two intrinsic structural matrices – property signature matrix $psig(V_{comp})$ and connectivity signature matrix $csig(V_{comp})$:

$$ssig(V_{comp}) = psig(V_{comp}) + csig(V_{comp})$$

$$psig(V_{comp}) = [\mathbf{p}_0 \ 0 \ \mathbf{p}_1 \ \mathbf{p}_0 \ 0 \ \mathbf{p}_2 \ \mathbf{p}_0 \ 0 \ \mathbf{p}_3 \ \dots \ \mathbf{p}_p \ 0 \ \mathbf{p}_q]$$

$$csig(V_{comp}) = [0 \ \mathbf{a}_{0,1} \ 0 \ 0 \ \mathbf{a}_{0,2} \ 0 \ 0 \ \mathbf{a}_{0,3} \ 0 \ \dots \ 0 \ \mathbf{a}_{p,q} \ 0]$$

Let us denote by $psig(P_1, V_{comp})$ the augmented semantic property signature of property P_1 with respect to V_{comp} . It is given with:

$$psig(P_0, V_{comp}) = [\mathbf{p}_0 \ 0 \ 0 \ \mathbf{p}_0 \ 0 \ 0 \ \mathbf{p}_0 \ 0 \ 0 \ \dots \ 0 \ 0 \ 0]$$

Similarly,

$$psig(P_1, V_{comp}) = [0 \ 0 \ \mathbf{p}_1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ \dots \ 0 \ 0 \ 0]$$

$$psig(P_q, V_{comp}) = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ \dots \ 0 \ 0 \ \mathbf{p}_q]$$

Then obviously:

$$psig(V_{comp}) = \sum_{k \in \mathbb{S}(V_{comp})} \sum_{i \in \mathbb{P}(V_k)} psig(P_i, V_{comp})$$

Here $\mathbb{S}(V_{comp})$ denotes the set of the indices of all semantic particles which the composite V_{comp} is composed from.

Another way to partition the signature matrix into block matrices is:

$$ssig(V_{comp}) = [\mathbf{V}_1 \ \mathbf{A}_{1,2} \ \mathbf{V}_2 \ \mathbf{A}_{1,3} \ \mathbf{V}_3 \ \dots \ \mathbf{A}_{6,8} \ \mathbf{V}_8 \ \mathbf{A}_{6,9} \ \mathbf{V}_9]$$

The block matrix \mathbf{V}_1 represents the property tree of the particle V_1 and it is given by:

$$\mathbf{V}_1 = [\mathbf{p}_0 \ \mathbf{a}_{0,1} \ \mathbf{p}_1 \ \mathbf{p}_0 \ \mathbf{a}_{0,2} \ \mathbf{p}_2 \ \mathbf{p}_0 \ \mathbf{a}_{0,3} \ \mathbf{p}_3 \ \dots \ \mathbf{p}_0 \ \mathbf{a}_{0,k} \ \mathbf{p}_k]$$

The block matrix $\mathbf{A}_{1,2}$ describes the connection between the particles V_1 and V_2 connecting the root property \mathbf{p}_0 of V_1 and the root property \mathbf{p}_{k+1} of V_2 . It is given with:

$$\mathbf{A}_{1,2} = [\mathbf{p}_0 \ \mathbf{a}_{0,k+1} \ \mathbf{p}_{k+1}] \text{ //TODO: expand it – the matrix structure is more complicated!}$$

Properties of the signature matrix

Here are some interesting properties of $ssig(V_{comp})$:

The number of rows N in $ssig(V_{comp})$ is $3 \times$ the number of arcs in the augmented property tree of V_{comp} .

The rank of

TO DO: finish the property section

Asymptotic closeness of semantic structures

Let us have two semantic structures S1 and S2.

$$\begin{aligned}ssig(S_1) &= [\mathbf{V}_{k_1} \mathbf{A}_{k_1, k_2} \mathbf{V}_{k_2} \mathbf{A}_{k_1, k_3} \mathbf{V}_{k_3} \dots \mathbf{A}_{k_p, k_q} \mathbf{V}_{k_q}] \\ssig(S_2) &= [\mathbf{V}_{l_1} \mathbf{A}_{l_1, l_2} \mathbf{V}_{l_2} \mathbf{A}_{l_1, l_3} \mathbf{V}_{l_3} \dots \mathbf{A}_{l_r, l_s} \mathbf{V}_{l_s}]\end{aligned}$$

Uniform asymptotic closeness

K -level uniform asymptotic closeness