LING3701/PSYCH3371: Lecture Notes 5
A Model of Complex Ideas in Associative Memory

We have seen how interconnected neurons can define mental states and cued associations.

This lecture will describe how mental states and cued associations can define complex ideas.

Contents

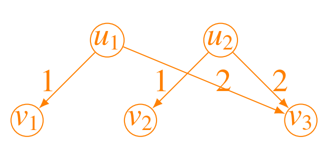
5.1 Previously: mental states and cued associations

Recall neural activation patterns and potentiated connection weights:

$$\overbrace{\begin{bmatrix} .71 \\ .0 \\ .71 \\ .0 \\ .0 \end{bmatrix}}^{\text{target } v_1} \overbrace{\begin{bmatrix} .0 & .58 & .0 & .58 & .58 \end{bmatrix}}^{\text{cue } u_1} + \overbrace{\begin{bmatrix} .0 \\ .58 \\ .58 \\ .0 \\ .58 \end{bmatrix}}^{\text{target } v_2} \overbrace{\begin{bmatrix} .0 & .0 & .71 & .71 & .0 \end{bmatrix}}^{\text{cue } u_2} = \overbrace{\begin{bmatrix} .0 & .41 & .0 & .41 & .41 \\ .0 & .0 & .41 & .41 & .0 \\ .0 & .41 & .41 & .82 & .41 \\ .0 & .0 & .0 & .0 & .0 \\ .0 & .0 & .41 & .41 & .0 \end{bmatrix}}^{\text{associations } M_1}$$

$$\overbrace{\begin{bmatrix} .58 \\ .58 \\ .0 \\ .58 \\ .0 \end{bmatrix}}^{\text{target } v_3} \overbrace{\begin{bmatrix} .0 & .58 & .58 & .0 & .58 \end{bmatrix}}^{\text{cue } u_1} + \overbrace{\begin{bmatrix} .58 \\ .58 \\ .0 \\ .58 \\ .0 \end{bmatrix}}^{\text{target } v_3} \overbrace{\begin{bmatrix} .0 & .0 & .71 & .71 & .0 \end{bmatrix}}^{\text{cue } u_2} = \overbrace{\begin{bmatrix} .0 & .33 & .74 & .41 & .33 \\ .0 & .33 & .74 & .41 & .33 \\ .0 & .0 & .0 & .0 & .0 \\ .0 & .33 & .74 & .41 & .33 \\ .0 & .0 & .0 & .0 & .0 \end{bmatrix}}^{\text{associations } M_2}$$

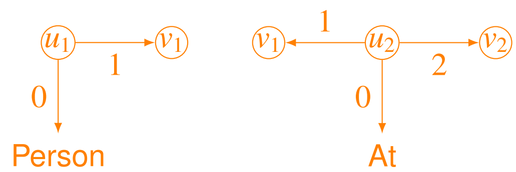
define coordinates of points (mental states) in mental space, linked by cued associations:



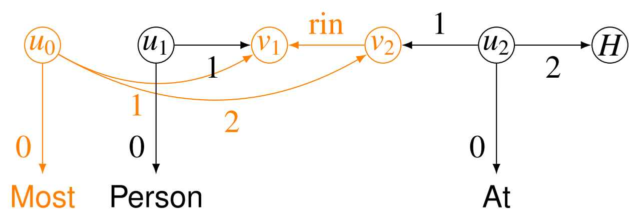
5.2 Cued associations can represent lambda calculus

We can use cued associations to build complex ideas, equivalent to lambda calculus:

- Predicates – Person v_1,   At v_1 v_2:



- Generalized quantifiers – Most (λ_{v_1} Person v_1) (λ_{v_2} At v_2 MyHill):

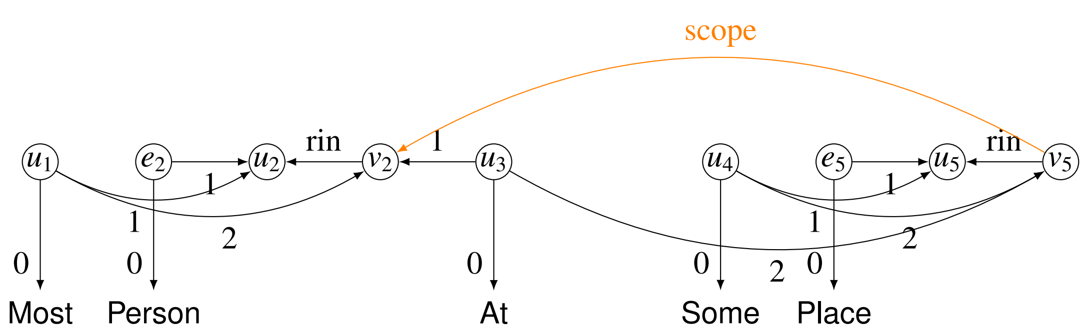


(Here 'rin' inherits the constraint of being a person from v_1 to v_2.)

5.3 Nesting

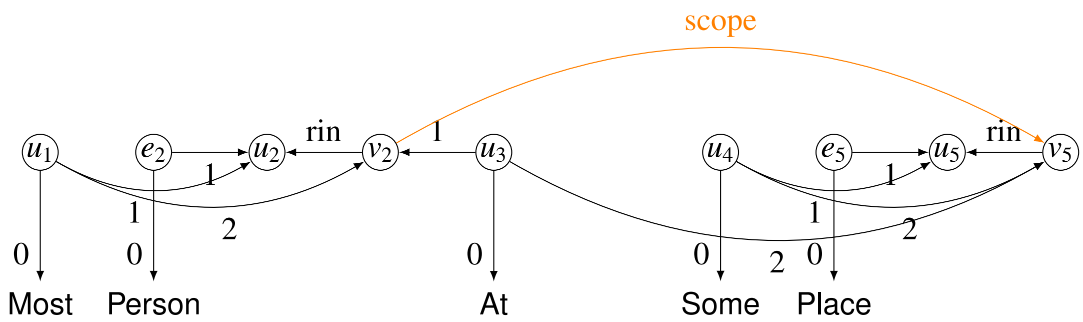
If multiple quantified referents are connected by predications, they must be nested somehow.

This distinguishes whether there is a set of places for each person or a set of people for each place:



In the above example, there is a generalization over at places for each person.

In the below example, there is a generalization over people for each at place (i.e. there is some place that everyone shares):



5.4 How are complex ideas experienced?

Remember, in this model a complex idea is a collection of cued associations in associative memory.

The entire idea is not all active at the same time.

How is such an idea experienced?

Just as we apprehend visual scenes by saccading from one physical fixation point to another, in this model we apprehend complex ideas by **transitioning** from one referential state to another, via cued associations.

So, as we think about people and places, there is always a 'you-are-here pointer' in the graph.

5.5 Cued association graphs translate into lambda calculus

Philosophers often define complex ideas using logical expressions in lambda calculus.

Lambda calculus is beyond the scope of this course, but if you happen to already know it...

The cued association graphs above can be translated into lambda calculus (not a cognitive process).

1. Add a lambda term to Γ for each predication in Γ with no outscoped variables or inheritances:

$$\frac{\Gamma, (f\ v_0\ v_1\ ..\ v\ ..\ v_N)\ ;\ \Delta}{\Gamma, (\lambda_v\ f\ v_0\ v_1\ ..\ v\ ..\ v_N)\ ;\ \Delta}\ f \notin Q,\ \forall_u\ (\mathbf{M}_{\text{scope}}\ u){=}v \notin \Gamma,\ \forall_{f\in\{\mathbf{M}_{\text{rin}},\mathbf{M}_{\text{cin}},\mathbf{M}_{\text{uin}}\}}\ (f\ v){=}u \notin \Gamma \qquad \text{(P)}$$

2. Conjoin lambda terms over the same variable in Γ (this combines modifier predications):

$$\frac{\Gamma, (\lambda_v\ \phi), (\lambda_v\ \psi)\ ;\ \Delta}{\Gamma, (\lambda_v\ \phi \wedge \psi)\ ;\ \Delta} \qquad \text{(C)}$$

3. Move terms in Γ with no missing predications, outscoped variables or inheritances to Δ:

$$\frac{\Gamma, (\lambda_v\ \psi)\ ;\ \Delta}{\Gamma\ ;\ (\lambda_v\ \psi), \Delta}\ \forall_{f'\notin Q}\ (f'\ ..\ v\ ..) \notin \Gamma,\ \forall_u\ (\mathbf{M}_{\text{scope}}\ u){=}v \notin \Gamma,\ \forall_{f\in\{\mathbf{M}_{\text{rin}},\mathbf{M}_{\text{cin}},\mathbf{M}_{\text{uin}}\}}\ (f\ v){=}u \notin \Gamma \qquad \text{(M)}$$

4. Add translations τ_f of quantifiers f in Γ over complete lambda terms in Δ:

$$\frac{\Gamma, (f\ p\ u\ v)\ ;\ (\lambda_u\ \phi), (\lambda_v\ \psi), \Delta}{\Gamma, (\tau_f\ (\lambda_u\ \phi)\ (\lambda_v\ \psi))\ ;\ (\lambda_u\ \phi), (\lambda_v\ \psi), \Delta}\ f \in Q,\ \forall_{f' \in \{\mathbf{M}_{\text{rin}}, \mathbf{M}_{\text{cin}}, \mathbf{M}_{\text{uin}}\}}\ (f' ..) = v \notin \Gamma,\ \forall_{f' \in Q}\ (f' ..\ v\ ..) \notin \Gamma \tag{Q1}$$

$$\frac{\Gamma, (\mathbf{M}_{\text{scope}}\ v) = v', (\tau_f\ (\lambda_u\ \phi)\ (\lambda_v\ \psi))\ ;\ \Delta}{\Gamma, (\lambda_{v'}\ \tau_f\ (\lambda_u\ \phi)\ (\lambda_v\ \psi))\ ;\ \Delta}\ \forall_{u'}\ (\mathbf{M}_{\text{scope}}\ u) = u' \notin \Gamma \tag{Q2}$$

$$\frac{\Gamma, (\mathbf{M}_{\text{scope}}\ u) = u', (\mathbf{M}_{\text{scope}}\ v) = v', (\tau_f\ (\lambda_u\ \phi)\ (\lambda_v\ \psi))\ ;\ \Delta}{\Gamma, (\mathbf{M}_{\text{scope}}\ u) = u', (\lambda_{v'}\ \tau_f\ (\lambda_u\ (\lambda_{u'}\ \phi)\ v')\ (\lambda_v\ \psi))\ ;\ \Delta} \tag{Q3}$$

5. Add a lambda term to Γ for each inheritance that is empty or from complete term in Δ:

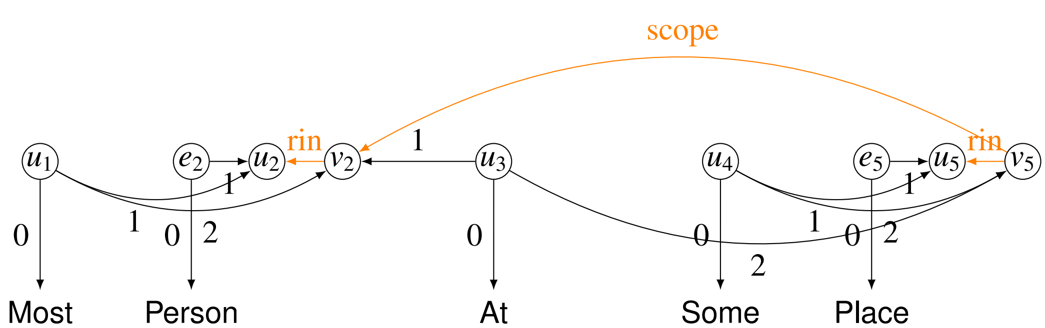
$$\frac{\Gamma, (f\ v) = u\ ;\ \Delta}{\Gamma, (f\ v) = u, (\lambda_u\ \mathsf{True})\ ;\ \Delta}\ f \in \{\mathbf{M}_{\text{rin}}, \mathbf{M}_{\text{cin}}\},\ \forall_{f' \notin Q}\ (f' ..\ u\ ..) \notin \Gamma \tag{I1}$$

$$\frac{\Gamma, (f\ v) = u\ ;\ (\lambda_u\ \phi), \Delta}{\Gamma, (\lambda_v\ (\lambda_u\ \phi)\ v)\ ;\ (\lambda_u\ \phi), \Delta}\ f \in \{\mathbf{M}_{\text{rin}}, \mathbf{M}_{\text{cin}}\},\ \forall_{u'}\ (\mathbf{M}_{\text{scope}}\ u) = u' \notin \Gamma \tag{I2}$$

$$\frac{\Gamma, (\mathbf{M}_{\text{scope}}\ u) = u', (f\ v) = u\ ;\ (\lambda_u\ \phi), \Delta}{\Gamma, (\mathbf{M}_{\text{scope}}\ u) = u', (\mathbf{M}_{\text{scope}}\ v) = u', (\lambda_v\ (\lambda_u\ \phi)\ v)\ ;\ (\lambda_u\ \phi), \Delta}\ f \in \{\mathbf{M}_{\text{rin}}, \mathbf{M}_{\text{cin}}\},\ \forall_{v'}\ (\mathbf{M}_{\text{scope}}\ v) = v' \notin \Gamma \tag{I3}$$

$$\frac{\Gamma, (\mathbf{M}_{\text{scope}}\ u) = u', (\mathbf{M}_{\text{scope}}\ v) = v', (f\ v) = u\ ;\ (\lambda_u\ \phi), \Delta}{\Gamma, (\mathbf{M}_{\text{scope}}\ u) = u', (\mathbf{M}_{\text{scope}}\ v) = v', (\lambda_v\ (\lambda_u\ (\lambda_{u'}\ \phi)\ v')\ v)\ ;\ (\lambda_u\ \phi), \Delta}\ f \in \{\mathbf{M}_{\text{rin}}, \mathbf{M}_{\text{cin}}\} \tag{I4}$$

For example, our graph:



translates into:

$(\mathsf{Most}\ p_1\ u_2\ v_2), (\mathbf{M}_{\text{scope}}\ v_5) = v_2, (\mathsf{Some}\ p_4\ u_5\ v_5), (\mathsf{Person}\ e_2\ u_2), (\mathsf{Place}\ e_5\ u_5), (\mathsf{At}\ u_3\ v_2\ v_5)\ ;$

$P\ (\mathsf{Most}\ p_1\ u_2\ v_2), (\mathbf{M}_{\text{scope}}\ v_5) = v_2, (\mathsf{Some}\ p_4\ u_5\ v_5), (\lambda_{u_2}\ \mathsf{Person}\ e_2\ u_2), (\lambda_{u_5}\ \mathsf{Place}\ e_5\ u_5), (\lambda_{v_5}\ \mathsf{At}\ u_3\ v_2\ v_5)\ ;$

$M\ (\mathsf{Most}\ p_1\ u_2\ v_2), (\mathbf{M}_{\text{scope}}\ v_5) = v_2, (\mathsf{Some}\ p_4\ u_5\ v_5)\ ;\ (\lambda_{u_2}\ \mathsf{Person}\ e_2\ u_2), (\lambda_{u_5}\ \mathsf{Place}\ e_5\ u_5), (\lambda_{v_5}\ \mathsf{At}\ u_3\ v_2\ v_5)$

$Q1\ (\mathsf{Most}\ p_1\ u_2\ v_2), (\mathbf{M}_{\text{scope}}\ v_5) = v_2, (\mathsf{Some}\ (\lambda_{u_5}\ \mathsf{Place}\ e_5\ u_5)\ (\lambda_{v_5}\ \mathsf{At}\ u_3\ v_2\ v_5))\ ;\ (\lambda_{u_2}\ \mathsf{Person}\ e_2\ u_2), (\lambda_{u_5}\ ...), (\lambda_{v_5}\ ...)$

$Q2\ (\mathsf{Most}\ p_1\ u_2\ v_2), (\lambda_{v_2}\ \mathsf{Some}\ (\lambda_{u_5}\ \mathsf{Place}\ e_5\ u_5)\ (\lambda_{v_5}\ \mathsf{At}\ u_3\ v_2\ v_5))\ ;\ (\lambda_{u_2}\ \mathsf{Person}\ e_2\ u_2), (\lambda_{u_5}\ ...), (\lambda_{v_5}\ ...)$

$M\ (\mathsf{Most}\ p_1\ u_2\ v_2)\ ;\ (\lambda_{v_2}\ \mathsf{Some}\ (\lambda_{u_5}\ \mathsf{Place}\ e_5\ u_5)\ (\lambda_{v_5}\ \mathsf{At}\ u_3\ v_2\ v_5)), (\lambda_{u_2}\ \mathsf{Person}\ e_2\ u_2), (\lambda_{u_5}\ ...), (\lambda_{v_5}\ ...)$

$Q1\ (\mathsf{Most}\ (\lambda_{u_2}\ \mathsf{Person}\ e_2\ u_2)\ (\lambda_{v_2}\ \mathsf{Some}\ (\lambda_{u_5}\ \mathsf{Place}\ e_5\ u_5)\ (\lambda_{v_5}\ \mathsf{eat}\ u_3\ v_2\ v_5)))\ ;\ (\lambda_{u_2}\ ...), (\lambda_{u_5}\ ...), (\lambda_{v_5}\ ...)$