

CNRS - Concours chercheurs 2025  
DR Section 53 - Concours n° 53/01

*Épistémologie des modèles distributionnels de langage  
par apprentissage machine*  
Explicabilité formelle et interprétabilité théorique

Juan Luis Gastaldi

[http://www.jlgastaldi.com/assets/gastaldi\\_cnrs\\_dr.pdf](http://www.jlgastaldi.com/assets/gastaldi_cnrs_dr.pdf)



# Parcours et travaux

|              |   |
|--------------|---|
| 1997-2007    | Recherche pré-doctorale<br>Argentine, France<br>(UNR, ENS, Paris 1, UPMC)           |
| 2008-2014    | Recherche doctorale<br>France<br>(Bordeaux Montaigne)                               |
| 2015-2022    | Recherche post-doctorale<br>France, Suisse, Tchéquie, USA<br>(ETH, MSCA, CUNY, CMU) |
| 2023-Présent | Nouvelle recherche doctorale<br>Suisse<br>(ETH Zurich)                              |

## Sciences Politiques

### Philosophie du langage et pensée formelle

#### Comment une science de l'homme est-elle possible?

- Héritage **critique** kantien contre le positivisme
- Dépassement du partage **anthropologie/ontologie**
- Anthropologie ou théorie de l'**expression**  
(Foucault, 1954; Deleuze, 1954)
- Alliance entre **savoirs formels** et philosophie critique contemporaine

- ◊ Gastaldi (2009, 2010, 2011, 2015, 2016b, 2019)

# Parcours et travaux

1997-2007 Recherche pré-doctorale  
Argentine, France  
(UNR, ENS, Paris 1, UPMC)

2008-2014 Recherche doctorale  
France  
(Bordeaux Montaigne)

2015-2022 Recherche post-doctorale  
France, Suisse, Tchéquie, USA  
(ETH, MSCA, CUNY, CMU)

2023-Présent Nouvelle recherche doctorale  
Suisse  
(ETH Zurich)

## Philosophie et histoire des sciences formelles

### Quelle critique pour les sciences formelles?

- Épistémologie historique
- La notion de *formel* a elle-même une histoire (récente)
- En devenant formelle, la mathématisation n'entraîne pas la naturalisation

- ◊ Gastaldi (2014, 2016a, 2022, 2024a, 2024b, 2024d)
- ◊ Gastaldi (ed.) (2024a, 2024b)

# Parcours et travaux

1997-2007 Recherche pré-doctorale  
Argentine, France  
(UNR, ENS, Paris 1, UPMC)

## Epistémologie des modèles de langage par apprentissage machine

2008-2014 Recherche doctorale  
France  
(Bordeaux Montaigne)

### Quelles pratiques formelles pour une théorie critique du langage?

- Analyse computationnelle de corpus textuels
- Modèles **distributionnels** de langage

2015-2022 Recherche post-doctorale  
France, Suisse, Tchéquie, USA  
(ETH, MSCA, CUNY, CMU)

- ◊ Gastaldi (2021, 2024c), Gastaldi, Moot, and Rétoré (2024), and Gastaldi and Pellissier (2021)

2023-Présent Nouvelle recherche doctorale  
Suisse  
(ETH Zurich)

# Parcours et travaux

1997-2007 Recherche pré-doctorale  
Argentine, France  
(UNR, ENS, Paris 1, UPMC)

2008-2014 Recherche doctorale  
France  
(Bordeaux Montaigne)

2015-2022 Recherche post-doctorale  
France, Suisse, Tchéquie, USA  
(ETH, MSCA, CUNY, CMU)

2023-Présent Nouvelle recherche doctorale  
Suisse  
(ETH Zurich)

## Fondements formels des modèles de language par apprentissage machine

### Quels fondements pour une science formelle du langage?

- Fondements **formels** des pratiques computationnelles  
(catégories, types)
- Fondements **structuraux** des principes distributionnels  
(segmentation, structure)

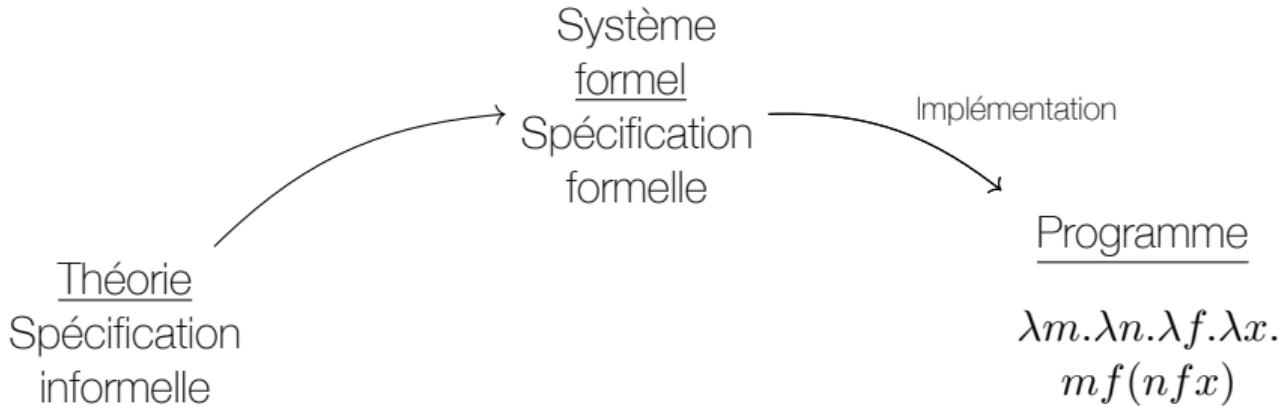
- ◊ Bradley et al. (2024), Gastaldi, Terilla, et al. (2024),  
Giulianelli et al. (2024), Vieira et al. (2024), and Zouhar  
et al. (2023a, 2023b)

# La structure implicite des données

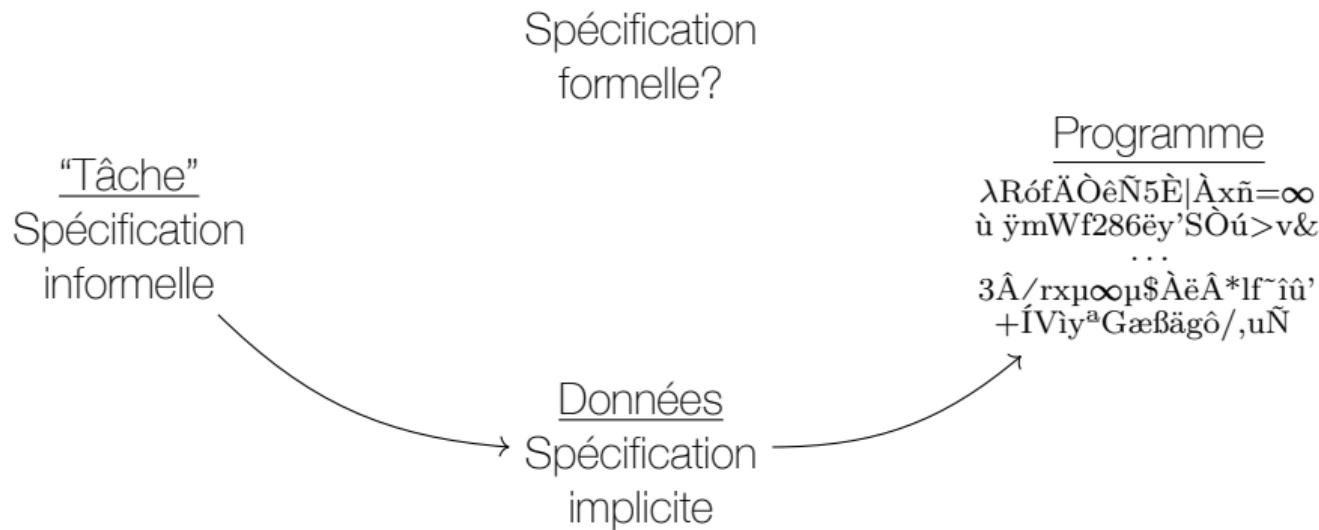
Programme

$$\begin{aligned} &\lambda m. \lambda n. \lambda f. \lambda x. \\ &mf(nfx) \end{aligned}$$

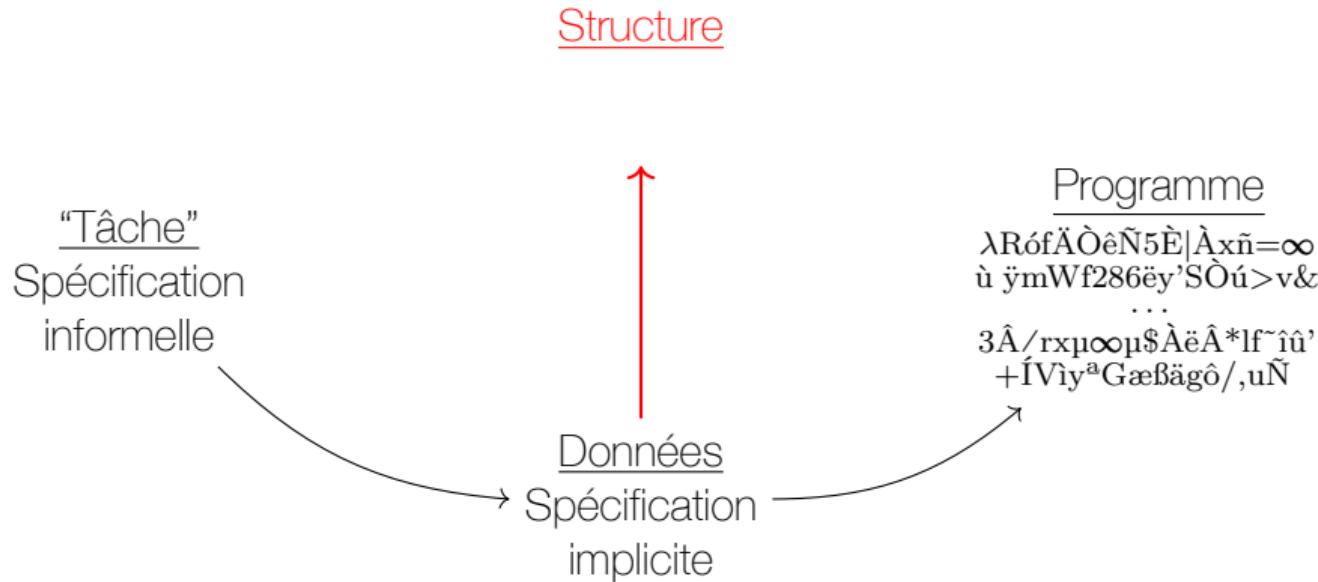
# La structure implicite des données



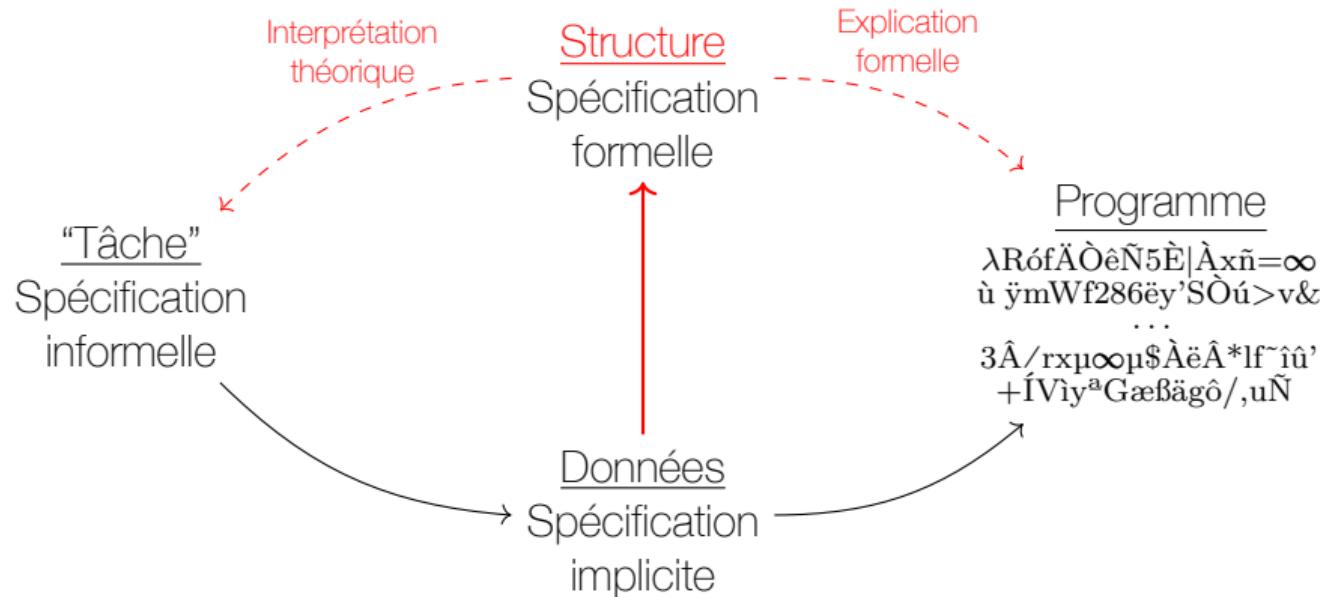
# La structure implicite des données



# La structure implicite des données



# La structure implicite des données



## Axe 1: Explicabilité formelle

## Tokenisation

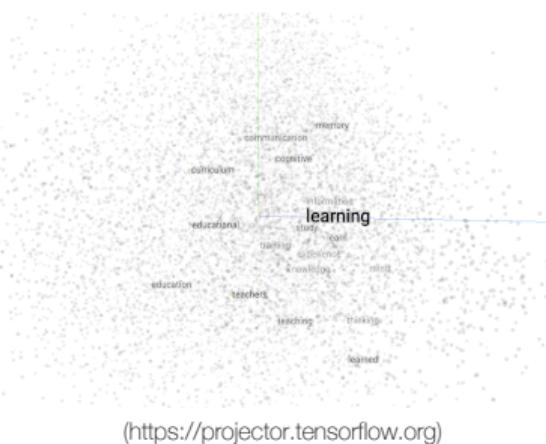
(Sennrich et al., 2016)

## Embedding

(Mikolov et al., 2013)

## Attention

(Vaswani et al., 2017)



# Epistemology of Machine Learning Distributional Language Models

(<https://tiktok-encoder.vercel.app>)

The figure is a network graph illustrating the relationships between different NLP models and their components. The nodes are represented by colored squares, and the edges are represented by lines connecting the nodes.

- Epistemic** (blue)
- Semantic** (green)
- Discourse** (yellow)
- Machine Learning** (orange)
- Distributional** (grey)
- Language** (purple)
- Models** (pink)

Connections (edges) are as follows:

- Epistemic → Semantic
- Epistemic → Discourse
- Machine Learning → Distributional
- Machine Learning → Language
- Machine Learning → Models

(<https://github.com/jessevig/bertviz>)

# Axe 1: Explicabilité formelle

Tokenisation

(Sennrich et al., 2016)

Embedding

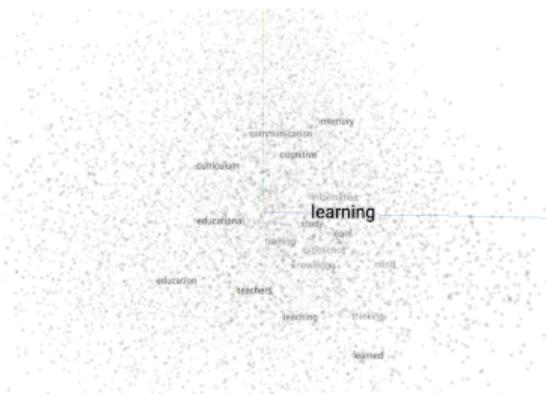
(Mikolov et al., 2013)

Attention

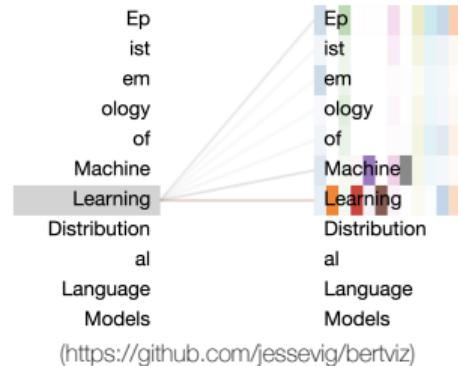
(Vaswani et al., 2017)

**Epistemology of Machine Learning  
Distributional Language Models**

(<https://tiktokizer.vercel.app>)



(<https://projector.tensorflow.org>)



# Embedding et SVD

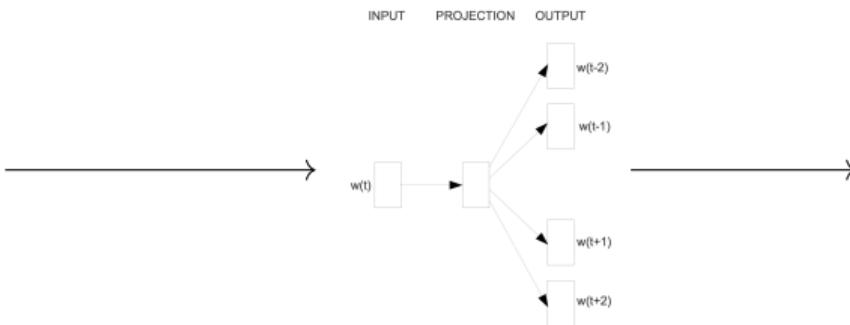


# Embedding et SVD



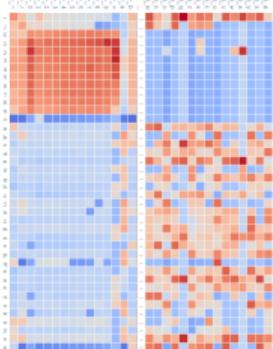
# WIKIPEDIA

The Free Encyclopedia



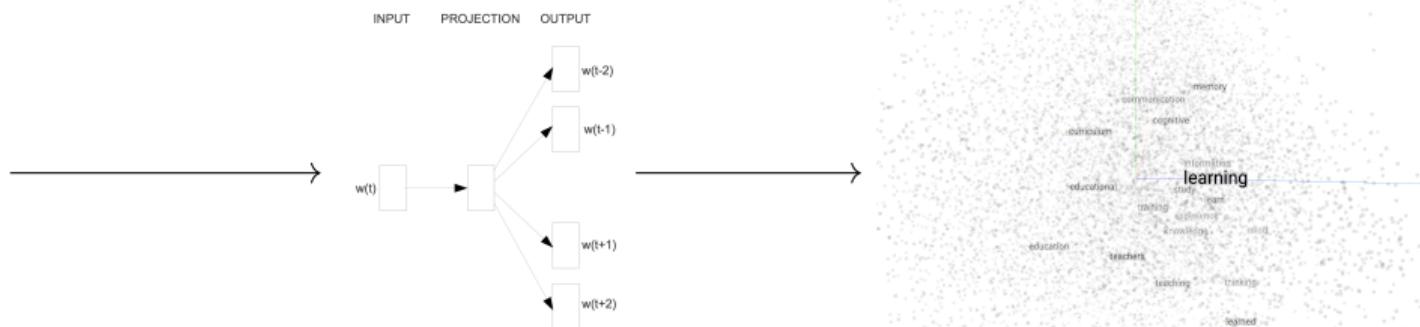
## Embedding et SVD

## Matrice PMI



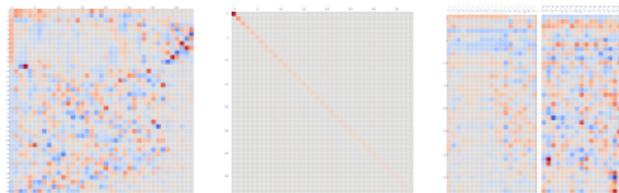
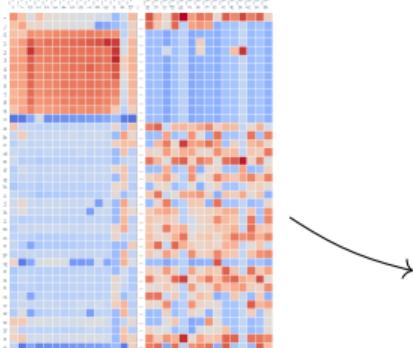
# WIKIPEDIA

The Free Encyclopedia



# Embedding et SVD

Matrice PMI

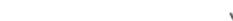
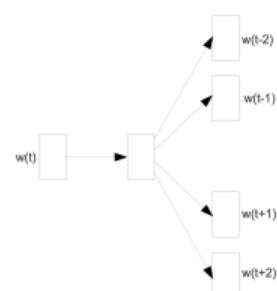


SVD



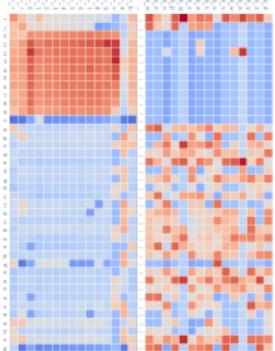
**WIKIPEDIA**  
The Free Encyclopedia

INPUT      PROJECTION      OUTPUT

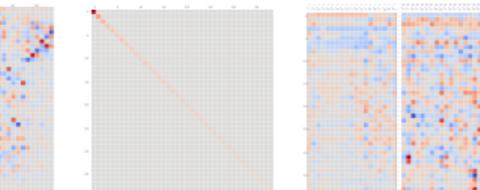
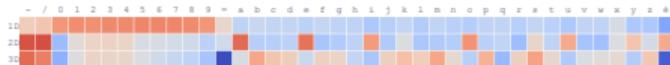


# Embedding et SVD

Matrice PMI



Vecteurs singuliers

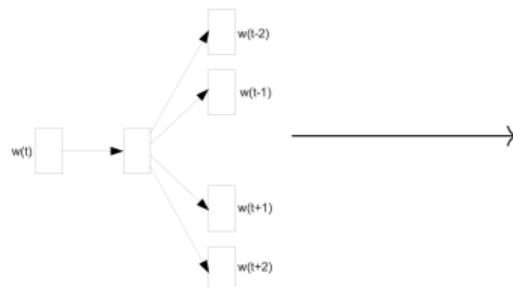


SVD



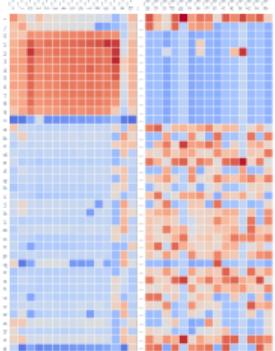
**WIKIPEDIA**  
The Free Encyclopedia

INPUT      PROJECTION      OUTPUT

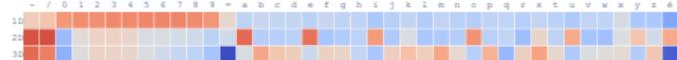


# Embedding et SVD

Matrice PMI

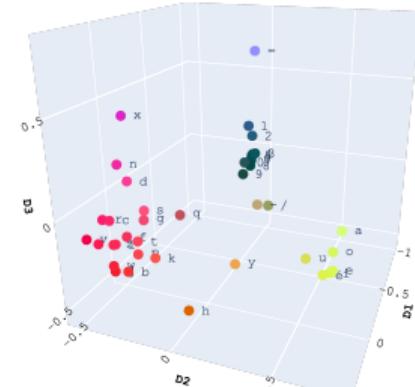


Vecteurs singuliers

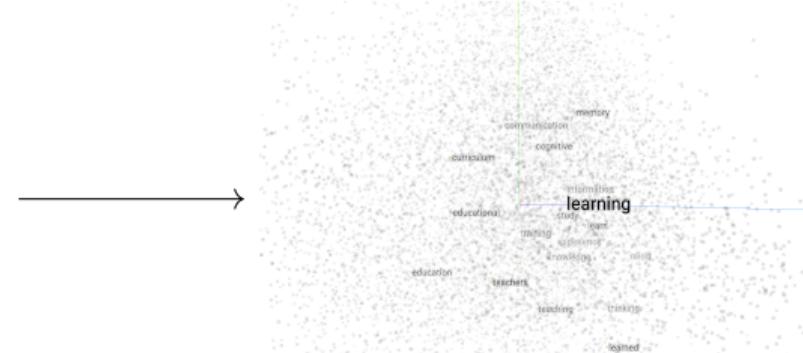
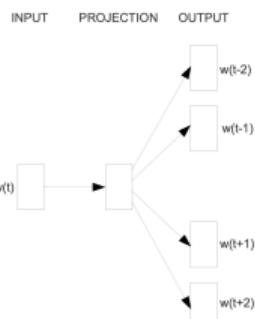


SVD

Embedding SVD



**WIKIPEDIA**  
The Free Encyclopedia



# De l'algèbre linéaire aux catégories

$$\begin{array}{ccc}
 X & \xrightarrow{M_x} & \mathbb{R}^Y \\
 \downarrow & M^* \nearrow & \uparrow \\
 \mathbb{R}^X & \xleftarrow{M_y} & Y
 \end{array}$$

$$\begin{array}{ccc}
 \mathbf{C} & \xrightarrow{\mathcal{M}_c} & (\mathbf{Set}^{\mathbf{D}})^{\text{op}} \\
 \downarrow \text{Yoneda} & \nearrow \mathcal{M}^* & \uparrow \text{Yoneda} \\
 \mathbf{Set}^{\mathbf{C}^{\text{op}}} & \xleftarrow{\mathcal{M}_d} & \mathbf{D}
 \end{array}$$

$$M_* M^*: \mathbb{R}^X \rightarrow \mathbb{R}^X$$

$$M^* M_*: \mathbb{R}^Y \rightarrow \mathbb{R}^Y$$

$$M_* M^* u_i = \lambda_i u_i$$

$$M^* M_* v_i = \lambda_i v_i$$

$$\mathcal{M}_* \mathcal{M}^*: \mathbf{Set}^{\mathbf{C}^{\text{op}}} \rightarrow \mathbf{Set}^{\mathbf{C}^{\text{op}}}$$

$$\mathcal{M}^* \mathcal{M}_*: (\mathbf{Set}^{\mathbf{D}})^{\text{op}} \rightarrow (\mathbf{Set}^{\mathbf{D}})^{\text{op}}$$

$$\text{Fix}(\mathcal{M}_* \mathcal{M}^*) := \{f \in \mathbf{Set}^{\mathbf{C}^{\text{op}}} \mid \mathcal{M}_* \mathcal{M}^*(f) \cong f\}$$

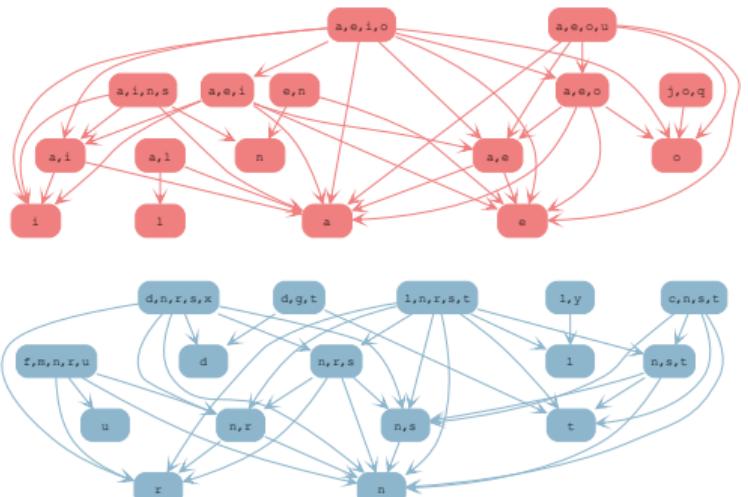
$$\text{Fix}(\mathcal{M}^* \mathcal{M}_*) := \{g \in (\mathbf{Set}^{\mathbf{D}})^{\text{op}} \mid \mathcal{M}^* \mathcal{M}_*(g) \cong g\}$$

# Structures catégoriques

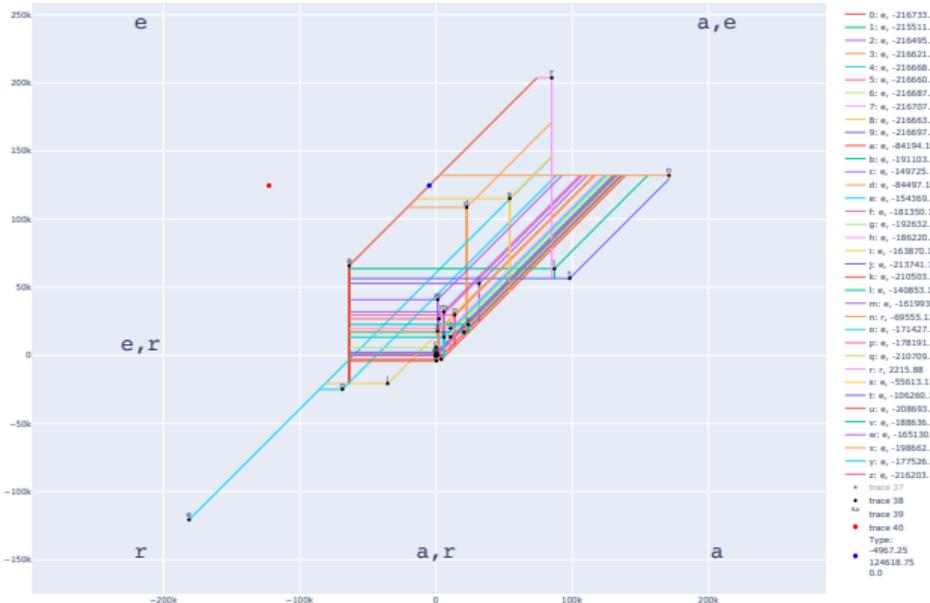
## Algèbre linéaire

|    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -  | / | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | = | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o | p | q | r | s | t | u | v | w | x | y | z | é |
| 1D |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 2D |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 3D |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

$$\mathcal{M}^*: \mathbf{2}^{\mathbf{C}^{\text{op}}} \leftrightarrows (\mathbf{2}^{\mathbf{D}})^{\text{op}}: \mathcal{M}_*$$



$$\mathcal{M}^*: \bar{\mathbb{R}}^{\mathbf{C}^{\text{op}}} \leftrightarrows (\bar{\mathbb{R}}^{\mathbf{D}})^{\text{op}}: \mathcal{M}_*$$



## Axe 2: Interprétabilité théorique

### Hypothèse distributionnelle

Le contenu des unités linguistiques est déterminé par leur **distribution** dans un corpus.

### Hypothèse structurale

Le contenu linguistique est l'effet d'une structure virtuelle dérivée des pratiques linguistiques dans une communauté.



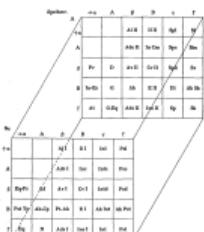
#### Axe 2: Interprétabilité théorique

## Hypothèse distributionnelle

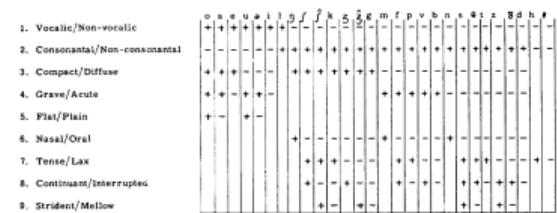
Le contenu des unités linguistiques est déterminé par leur **distribution** dans un corpus.

## Hypothèse structurale

Le contenu linguistique est l'effet d'une structure virtuelle dérivée des pratiques linguistiques dans une communauté.



(Hjelmslev, 1935)



(Jakobson et al., 1952)

(Harris, 1960)

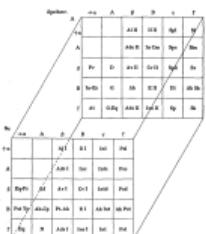
| Table 8.<br>Vowel x binary final cluster (inf. sect. 84). |     |    |   |   |   |   |   |        |    |    |    |    |    |    |    |
|---|-----|----|---|---|---|---|---|--------|----|----|----|----|----|----|----|
|   | n   | m  | b | v | r | w | y | clust. | sw | sh | ch | th | rh | sl | m  |
| a   | 5   | 10 | 3 | 9 | 8 | 2 | 1 | s      | 8  | 16 | 20 | 14 | 9  | 8  | 11 |
|   | 6   | 2  | 1 | 3 | 2 | 2 | 1 | -      | 9  | 3  | 9  | 6  | -  | 3  | 3  |
|   | 7   | 6  | 5 | 1 | 3 | 2 | 4 | i      | 13 | 11 | 20 | 8  | 2  | 11 | 6  |
| o   | 3   | 2  | 2 | 4 | 4 | 2 | 1 | -      | 1  | 2  | 2  | 2  | -  | 4  | 12 |
|   | 4   | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 6  | 9  |
|   | 5   | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 4  | 4  |
|   | 6   | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 1  | 1  |
|   | 7   | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 3  | 2  |
|   | 8   | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 1  | 1  |
|   | 9   | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 6  | 6  |
|   | 10  | 1  | 1 | 2 | 1 | 1 | 1 | -      | 1  | 2  | 2  | 2  | -  | 4  | 4  |
|   | 11  | 1  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 12  | 1  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 13  | 1  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 14  | 1  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 15  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 16  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 17  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 18  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 19  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 20  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 21  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 22  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 23  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 24  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 25  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 26  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 27  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 28  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 29  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 30  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 31  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 32  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 33  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 34  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 35  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 36  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 37  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 38  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 39  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 40  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 41  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 42  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 43  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 44  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 45  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 46  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 47  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 48  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 49  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 50  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 51  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 52  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 53  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 54  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 55  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 56  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 57  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 58  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 59  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 60  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 61  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 62  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 63  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 64  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 65  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 66  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 67  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 68  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 69  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 70  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 71  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 72  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 73  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 74  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 75  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 76  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 77  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 78  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 79  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 80  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 81  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 82  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 83  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 84  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 85  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 86  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 87  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 88  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 89  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 90  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 91  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 92  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 93  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 94  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 95  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 96  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 97  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 98  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 99  | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 100 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 101 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 102 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 103 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 104 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 105 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 106 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 107 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 108 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 109 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 110 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 111 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 112 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 113 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 114 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 115 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 116 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 117 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   | 118 | 2  | 1 | 2 | 1 | 1 | 1 | -      | 2  | 9  | 11 | 8  | 1  | 3  | 6  |
|   |     |    |   |   |   |   |   |        |    |    |    |    |    |    |    |

(Spang-Hanssen, 1959)

# Axe 2: Interprétabilité théorique

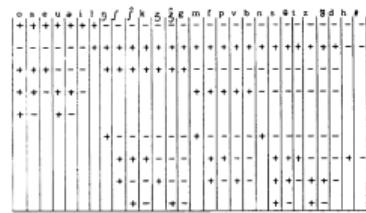
## Hypothèse distributionnelle

Le contenu des unités linguistiques est déterminé par leur distribution dans un corpus.



(Hjelmslev, 1935)

1. Vocalic/Non-vocalic
2. Consonantal/Non-consonantal
3. Compact/Diffuse
4. Grave/Acute
5. Flat/Plain
6. Nasal/Oral
7. Tense/Lax
8. Continuant/interrupted
9. Strident/Mellow



(Jakobson et al., 1952)

| Environnement |   |   |   |   |   |   |   |   |   |    |    |    |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|
|               | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1             | ✓ |   |   |   |   |   |   |   |   |    |    |    |
| 2             |   | ✓ |   |   |   |   |   |   |   |    |    |    |
| 3             |   |   | ✓ |   |   |   |   |   |   |    |    |    |
| 4             |   |   |   | ✓ |   |   |   |   |   |    |    |    |
| 5             |   |   |   |   | ✓ |   |   |   |   |    |    |    |
| 6             |   |   |   |   |   | ✓ |   |   |   |    |    |    |
| 7             |   |   |   |   |   |   | ✓ |   |   |    |    |    |
| 8             |   |   |   |   |   |   |   | ✓ |   |    |    |    |
| 9             |   |   |   |   |   |   |   |   | ✓ |    |    |    |
| 10            |   |   |   |   |   |   |   |   |   | ✓  |    |    |
| 11            |   |   |   |   |   |   |   |   |   |    | ✓  |    |
| 12            |   |   |   |   |   |   |   |   |   |    |    | ✓  |

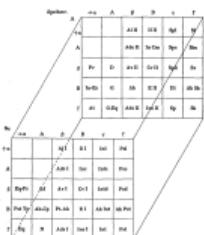
(Harris, 1960)

| Table 8.<br>Vowel × binary class cluster (cf. sect. 8d). |   |    |   |   |   |   |   |   |    |    |    |     |
|--|---|----|---|---|---|---|---|---|----|----|----|-----|
|  | 1 | 2  | 3 | 4 | 5 | 6 | 7 | 8 | 9  | 10 | 11 | 12  |
| 1  | 5 | 10 | 1 | 2 | 9 | 8 | 6 | 8 | 16 | 20 | 14 | 9   |
| 2  |   | 9  | 5 | 2 | 1 | 3 | 7 | 4 | 13 | 11 | 6  | 5   |
| 3  |   | 7  | 6 | 9 | 5 | 2 | 1 | 1 | 1  | 11 | 6  | 5   |
| 4  |   | 3  | 2 | 5 | 4 | 2 | 1 | 1 | 1  | 2  | 3  | 2   |
| 5  |   | 2  | 1 | 2 | 5 | 4 | 1 | 1 | 1  | 12 | 3  | 2   |
| 6  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 7  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 8  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 9  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 10   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 11   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 12   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 13   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 14   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 15   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 16   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 17   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 18   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 19   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 20   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 21   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 22   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 23   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 24   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 25   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 26   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 27   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 28   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 29   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 30   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 31   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 32   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 33   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 34   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 35   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 36   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 37   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 38   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 39   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 40   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 41   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 42   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 43   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 44   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 45   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 46   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 47   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 48   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 49   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 50   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 51   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 52   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 53   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 54   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 55   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 56   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 57   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 58   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 59   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 60   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 61   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 62   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 63   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 64   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 65   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 66   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 67   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 68   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 69   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 70   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 71   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 72   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 73   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 74   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 75   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 76   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 77   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 78   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 79   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 80   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 81   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 82   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 83   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 84   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 85   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 86   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 87   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 88   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 89   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 90   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 91   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 92   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 93   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 94   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 95   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 96   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 97   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 98   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 99   |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 100  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 101  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 102  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 103  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 104  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 105  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 106  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 107  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 108  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 109  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 110  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 111  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 112  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 113  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 114  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 115  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 116  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 117  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 118  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 119  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 120  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 121  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 122  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2   |
| 123  |   | 2  | 1 | 1 | 2 | 5 | 4 | 1 | 1  | 1  | 1  | 2</ |

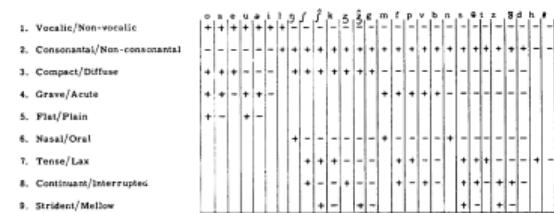
#### Axe 2: Interprétabilité théorique

## Hypothèse distributionnelle

Le contenu des unités linguistiques est déterminé par leur **distribution** dans un corpus.



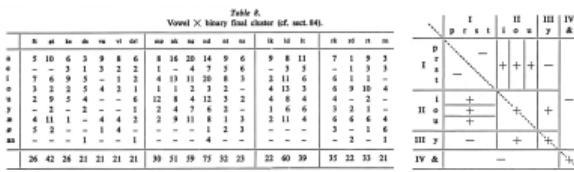
(Hjelmslev, 1935)



(Jakobson et al., 1952)



(Harris, 1960)



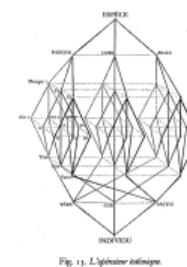
(Spang-Hanssen, 1959)

## Hypothèse structurale

Le contenu linguistique est l'effet d'une **structure** virtuelle dérivée des pratiques linguistiques dans une communauté.



(Lévi-Strauss, 1949)



(Lévi-Strauss, 1962)



(Bourdieu, 1979)

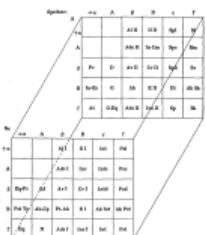


(Bourdieu, 1994)

# Axe 2: Interprétabilité théorique

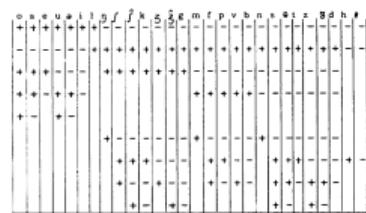
## Hypothèse distributionnelle

Le contenu des unités linguistiques est déterminé par leur distribution dans un corpus.



(Hjelmslev, 1935)

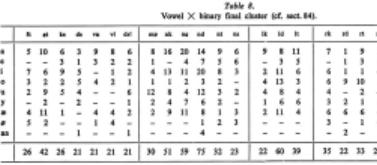
1. Vocalic/Non-vocalic
2. Consonantal/Non-consonantal
3. Compact/Diffuse
4. Grave/Acute
5. Flat/Plain
6. Nasal/Oral
7. Tense/Lax
8. Continuant/interrupted
9. Strident/Mellow



(Jakobson et al., 1952)



(Harris, 1960)



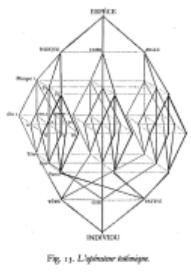
(Spang-Hanßen, 1959)

## Hypothèse structurale

Le contenu linguistique est l'effet d'une structure virtuelle dérivée des pratiques linguistiques dans une communauté.

| Répondant                  | État + énergie | équation | Fonction |
|----------------------------|----------------|----------|----------|
| Prix                       | +              | +        | -        |
| Photos inférieures         |                |          |          |
| Sens                       |                | +OK      |          |
| Choses de la nature        |                | +        | +        |
| Etats de la forme          |                | +        | +        |
| Espace et temps, distances |                | +        | +        |
| espace et temps            |                | +        | +        |
| Chômage                    |                | +        | +        |
| Population                 |                | +        | +        |
| Productions de la terre    |                | +        | +        |
| Matières premières         |                | +        | +        |
| Religion                   |                | +        | +        |
| Monnaie                    |                | +        | +        |
| Chiffres                   |                | +        | +        |
| Propriétaires de la terre  |                | +        | +        |
| Religions                  |                | +        | +        |
| Monnaies                   |                | +        | +        |
| Chiffres                   |                | +        | +        |
| Population                 |                | +        | +        |
| Productions de la terre    |                | +        | +        |
| Matières premières         |                | +        | +        |
| Religion                   |                | +        | +        |
| Propriétaires de la terre  |                | +        | +        |
| Monnaies                   |                | +        | +        |
| Chiffres                   |                | +        | +        |

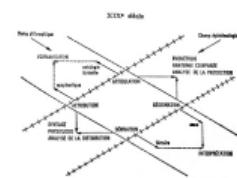
(Lévi-Strauss, 1949)



(Lévi-Strauss, 1962)



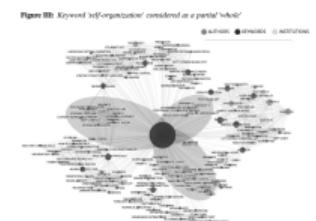
(Bourdieu, 1979)



(Foucault, 1966)



(Bourdieu, 1994)



(Latour et al., 2012)

## LIPN, UMR 7030 (Paris)

- ◊ Équipe LoCal (Logique et Calcul)
- ◊ Accent sur les **fondements**  
(théorie des types, théorie de catégories, TAL)
- ◊ Rapprochement de différentes équipes  
(eg. axe "Sc. des données")
- ◊ Forte interdisciplinarité  
(santé, linguistique, physique, philosophie)

## LIRMM, UMR 5506 (Montpellier)

- ◊ Équipe **TEXTE** (Exploration et exploitation de données textuelles)
- ◊ Accent sur les **applications**  
(grammaires catégorielles, TAL, th. des types)
- ◊ Activités **transversales**  
(eg. axe "IA et Sc. des données")
- ◊ Forte interdisciplinarité  
(projet Muse: "Nourrir, Soigner, Protéger")

## Dans les deux cas

- ◊ Collaboration et contact avec des membres et la direction
- ◊ Intégration des aspects **épistémologiques** et **sociétaux** dans la recherche
- ◊ Présentation de mon travail aux équipes

## Publications en cours

- ◊ “Content from expressions” (accepté à *Synthèse*)
- ◊ “LMs over Canonical BPEs” (soumis à ICML)
- ◊ “Distributional typing” (en cours)
- ◊ Chapitre sur LLMs (en cours, Oxford Handbook)

## Collaborations et projets

- ◊ Cluster “Foundations of AI”  
(CUNY, Simons Foundation)
- ◊ Projet “Human Forms”  
(soumis à E. Schmidt Foundation)

## Conférences à venir

- ◊ ICLR 2025 (Singapour, 24-28/04)
- ◊ Séminaire “IA et créativité” (Strasbourg, 13/05)
- ◊ Symposium “Chat Token Vector” (Venise, 11-13/06 - Keynote)
- ◊ Séminaire “Linguistics and Language Models” (Dagstuhl, 21-25/07)

# Références I

- Bourdieu, P. (1979). *La distinction: Critique sociale du jugement*. Éditions de Minuit.
- Bourdieu, P. (1994). *Raisons pratiques: Sur la théorie de l'action*. Éditions du Seuil.
- Bradley, T.-D., Gastaldi, J. L., & Terilla, J. (2024). The structure of meaning in language: Parallel narratives in linear algebra and category theory. *Notices of the American Mathematical Society*.  
<https://api.semanticscholar.org/CorpusID:263613625>
- Deleuze, G. (1954). Jean Hyppolite, *Logique et existence*. In D. Lapoujade (Ed.), *L'île déserte et autres textes. textes et entretiens 1953-1974* (pp. 18–23). Éditions de Minuit.
- Foucault, M. (1954). Introduction. (J. Verdeaux, Trans.). In L. Binswanger (Ed.), *Le Rêve et l'Existence* (pp. 9–128). Desclée de Brouwer.
- Foucault, M. (1966). *Les mots et les choses : Une archéologie des sciences humaines*. Gallimard.
- Gastaldi, J. L. (2009). La politique avant l'être. deleuze, ontologie et politique. *Cités*, (40), 59–73.  
<http://www.jstor.org/stable/40599521>
- Gastaldi, J. L. (2010). Qu'est-ce qu'une figure? Lyotard et le problème du fondement d'une théorie de l'expression. In C. Pagès (Ed.), *Lyotard à nanterre*. Klincksieck.
- Gastaldi, J. L. (2011). L'esthétique au sein des mots: Discours, figure, ou le renouvellement du projet critique. In P. Maniglier (Ed.), *Le moment philosophique des années 1960 en france* (pp. 537–556). Presses Universitaires de France.
- Gastaldi, J. L. (2014, September). *Une archéologie de la logique du sens : arithmétique et contenu dans le processus de mathématisation de la logique au XIXe siècle* (Publication No. 2014BOR30035) [Theses]. Université Michel de Montaigne - Bordeaux III. <https://tel.archives-ouvertes.fr/tel-01174485>
- Gastaldi, J. L. (2015). Le sens d'une Logique du Sens: Deleuze, Frege et le rendez-vous manqué. In A. Jdey (Ed.), *Gilles deleuze: Politiques de la philosophie* (pp. 205–227). Métis Press.

## Références II

- Gastaldi, J. L. (2016a). Frege's *Habilitationsschrift*: Magnitude, Number and the Problems of Computability. In F. Gadducci & M. Tavosanis (Eds.), *History and philosophy of computing* (pp. 168–185). Springer International Publishing.
- Gastaldi, J. L. (2016b). Par-delà métaphore et littéralité. Le statut des mathématiques dans l'œuvre de Deleuze. *Implications Philosophiques*.  
<http://www.implications-philosophiques.org/actualite/une/par-dela-metaphore-et-litteralite/>
- Gastaldi, J. L. (2019). L'archéologie à l'épreuve des savoirs formels. Mathématiques et formalisation dans le projet d'une archéologie des savoirs. In J.-F. Braunstein, I. M. Diez, & M. Vagelli (Eds.), *L'épistémologie historique. histoire et méthodes*. Éditions de la Sorbonne.
- Gastaldi, J. L. (2021). Why Can Computers Understand Natural Language? *Philosophy & Technology*, 34(1), 149–214.  
<https://doi.org/10.1007/s13347-020-00393-9>
- Gastaldi, J. L. (2022). Boole's Untruth Tables: The Formal Conditions of Meaning Before the Emergence of Propositional Logic. In J.-Y. Béziau, J.-P. Desclés, A. Moktefi, & A. C. Pascu (Eds.), *Logic in question: Talks from the annual sorbonne logic workshop (2011- 2019)* (pp. 119–149). Springer International Publishing.  
[https://doi.org/10.1007/978-3-030-94452-0\\_7](https://doi.org/10.1007/978-3-030-94452-0_7)
- Gastaldi, J. L. (2024a). Computing Cultures: Historical and Philosophical Perspectives. *Minds and Machines*, 34(1), 1–10. <https://doi.org/10.1007/s11023-023-09653-x>
- Gastaldi, J. L. (2024b). De Morgan's De Morgan's Laws Duality in the Emergence of Formal Logic. In R. Krömer & E. Haffner (Eds.), *Duality in 19th and 20th century mathematical thinking* (pp. 61–99). Springer Nature Switzerland. [https://doi.org/10.1007/978-3-031-59797-8\\_3](https://doi.org/10.1007/978-3-031-59797-8_3)

## Références III

- Gastaldi, J. L. (2024c). How to Do Maths with Words: Neural Machine Learning Applications to Mathematics and Their Philosophical Significance. In B. Sriraman (Ed.), *Handbook of the history and philosophy of mathematical practice* (pp. 3191–3226). Springer International Publishing.  
[https://doi.org/10.1007/978-3-031-40846-5\\_142](https://doi.org/10.1007/978-3-031-40846-5_142)
- Gastaldi, J. L. (2024d). Introduction to the Semiology of Mathematical Practice. In B. Sriraman (Ed.), *Handbook of the history and philosophy of mathematical practice* (pp. 2955–2970). Springer International Publishing.  
[https://doi.org/10.1007/978-3-031-40846-5\\_130](https://doi.org/10.1007/978-3-031-40846-5_130)
- Gastaldi, J. L. (Forthcoming 2024c). Content from Expressions. The Place of Textuality in Deep Learning Approaches to Mathematics. *Synthese (under review)*.
- Gastaldi, J. L., Moot, R., & Rétoré, C. (2024). Le contexte en traitement automatique des langues. In G. Hassler (Ed.), *Le contexte en question*. Iste.
- Gastaldi, J. L., & Pellissier, L. (2021). The calculus of language: explicit representation of emergent linguistic structure through type-theoretical paradigms. *Interdisciplinary Science Reviews*, 46(4), 569–590.  
<https://doi.org/10.1080/03080188.2021.1890484>
- Gastaldi, J. L., Terilla, J., Malagutti, L., DuSell, B., Vieira, T., & Cotterell, R. (2024). The Foundations of Tokenization: Statistical and Computational Concerns. <https://arxiv.org/abs/2407.11606>
- Gastaldi (ed.), J. L. (Ed.). (2024a). Computing Cultures: Historical and Philosophical Perspectives [Special Issue]. *Minds and Machines*, 34(1). Special Issue. <https://link.springer.com/collections/dgcffbghba>
- Gastaldi (ed.), J. L. (2024b). Section: Semiology of Mathematical Practice. In B. Sriraman (Ed.), *Handbook of the History and Philosophy of Mathematical Practice* (pp. 2955–3226). Springer International Publishing.  
<https://doi.org/10.1007/978-3-031-40846-5>
- Girard, J.-Y. (2006). *Le point aveugle: Cours de logique. vers la perfection*. Editions Hermann.

# Références IV

- Giulianelli, M., Malagutti, L., Gastaldi, J. L., DuSell, B., Vieira, T., & Cotterell, R. (2024). On the Proper Treatment of Tokenization in Psycholinguistics [To appear in the Proceedings of EMNLP 2024].  
<https://arxiv.org/abs/2410.02691>
- Harris, Z. (1960). *Structural linguistics*. University of Chicago Press.
- Hjelmslev, L. (1935). *La catégorie des cas*. Wilhelm Fink Verlag.
- Hjelmslev, L. (1975). *Résumé of a Theory of Language*. Nordisk Sprog-og Kulturforlag.
- Jakobson, R., Fant, G. M., & Halle, M. (1952). *Preliminaries to speech analysis: The distinctive features and their correlates*. MIT Press.
- Latour, B., Jensen, P., Venturini, T., Grauwin, S., & Boullier, D. (2012). 'The whole is always smaller than its parts' - a digital test of Gabriel Tardes' monads. *The British Journal of Sociology*, 63(4), 590–615.
- Lévi-Strauss, C. (1949). *Les structures élémentaires de la parenté*. Presses Universitaires de France.
- Lévi-Strauss, C. (1962). *La pensée sauvage*. Plon.
- Mikolov, T., Sutskever, I., Chen, K., Corrado, G., & Dean, J. (2013). Distributed representations of words and phrases and their compositionality. *CoRR*, abs/1310.4546.
- Sennrich, R., Haddow, B., & Birch, A. (2016). Neural machine translation of rare words with subword units. *Proceedings of the 54th Annual Meeting of the ACL*, 1715–1725.
- Spang-Hanssen, H. (1959). *Probability and structural classification in language description*. Rosenkilde; Bagger.
- Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., Kaiser, Ł., & Polosukhin, I. (2017). Attention is all you need. In I. Guyon, U. V. Luxburg, S. Bengio, H. Wallach, R. Fergus, S. Vishwanathan, & R. Garnett (Eds.), *Advances in neural information processing systems* (Vol. 30). Curran Associates, Inc. [https://proceedings.neurips.cc/paper\\_files/paper/2017/file/3f5ee243547dee91fb053c1c4a845aa-Paper.pdf](https://proceedings.neurips.cc/paper_files/paper/2017/file/3f5ee243547dee91fb053c1c4a845aa-Paper.pdf)

## Références V

- Vieira, T., LeBrun, B., Giulianelli, M., Gastaldi, J. L., DuSell, B., Terilla, J., O'Donnell, T. J., & Cotterell, R. (2024). From language models over tokens to language models over characters. <https://arxiv.org/abs/2412.03719>
- Zouhar, V., Meister, C., Gastaldi, J. L., Du, L., Sachan, M., & Cotterell, R. (2023b). Tokenization and the Noiseless Channel. *Proceedings of the 61st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, 5184–5207. <https://doi.org/10.18653/v1/2023.acl-long.284>
- Zouhar, V., Meister, C., Gastaldi, J. L., Du, L., Vieira, T., Sachan, M., & Cotterell, R. (2023a). A Formal Perspective on Byte-Pair Encoding. *Findings of the Association for Computational Linguistics: ACL 2023*, 598–614. <https://doi.org/10.18653/v1/2023.findings-acl.38>

CNRS - Concours chercheurs 2025  
DR Section 53 - Concours n° 53/01

*Épistémologie des modèles distributionnels de langage  
par apprentissage machine*  
Explicabilité formelle et interprétabilité théorique

Juan Luis Gastaldi

[http://www.jlgastaldi.com/assets/gastaldi\\_cnrs\\_dr.pdf](http://www.jlgastaldi.com/assets/gastaldi_cnrs_dr.pdf)



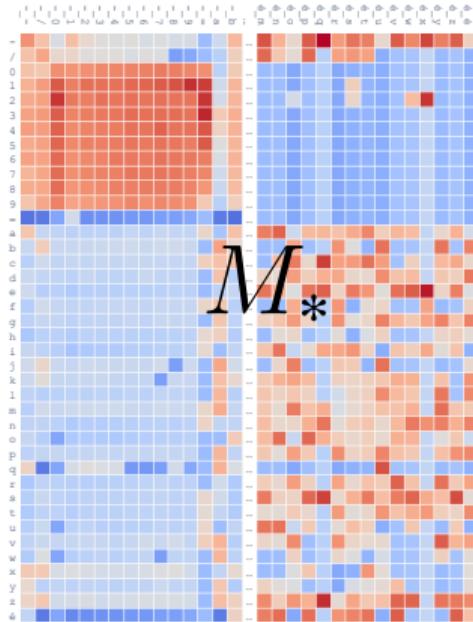
# Axe 1: Objectifs

- ◊ Short Term
  - ◊ Systematizing, Formalizing, and Testing
  - ◊ Enriching Over  $\bar{\mathbb{R}}$
  - ◊ Defining a Product over the Nucleus
- ◊ Medium Term
  - ◊ Characterizing Tokenization from a Structural Standpoint
  - ◊ Scaling for Real World Data
- ◊ Long Term
  - ◊ Assessment of state-of-the-art DNN language models in the light of the proposed formal framework (performance and efficiency comparison, limit properties, verification guarantees).
  - ◊ Exploration of other base categories and measures.
  - ◊ Further optimization.
  - ◊ Development of software packages and a usable integrated software framework for the scientific community.

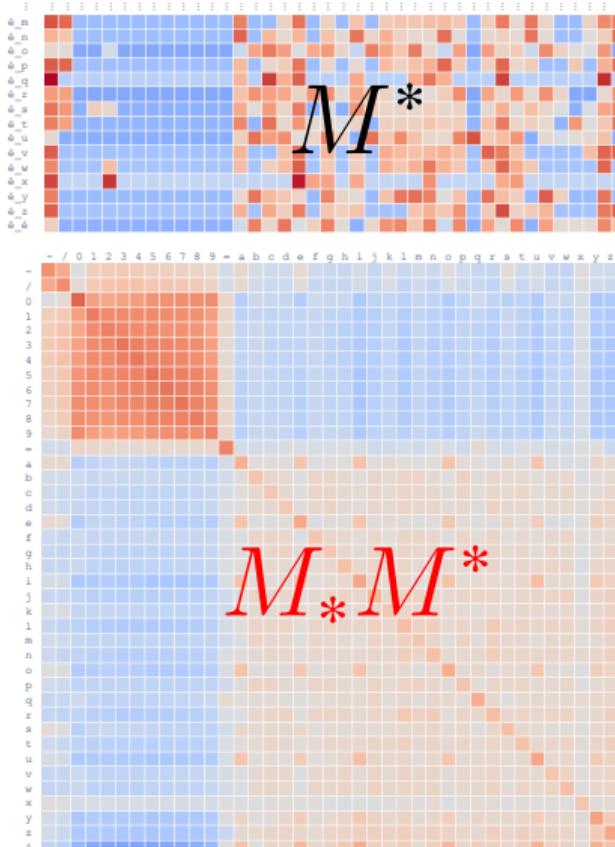
## Axe 2: Objectifs

- ◊ Short Term
  - ◊ Characterizing Epistemological Stakes through a Historical Lens
  - ◊ Interpreting Paradigms as Types
  - ◊ Addressing Semantic Aspects
- ◊ Medium Term
  - ◊ Revisiting the Theory of Distinctive Features and Exploring Possible Extensions
  - ◊ Studying the Syntactic properties of the Nucleus' compositional Structure
- ◊ Long Term
  - ◊ The study of pragmatic limits to the formal content captured by the set of types definable through a structural analysis of linguistic data.
  - ◊ The evaluation of the effects on ML models of the bias towards written language.
  - ◊ The assessment of other classically structuralist principles such as segmentation and double patterning.
  - ◊ A critique of the Symbolist-Connectionist debate in light of the results established in this program.
  - ◊ The exploration of possible applications of the framework proposed to non-linguistic data (sounds, images, formal languages, etc.)
  - ◊ The study of the conditions for the generalization of the use of the model proposed across scientific disciplines, specially in the Social Sciences and the Humanities.

# $M_* M^*$ comme matrice de covariance



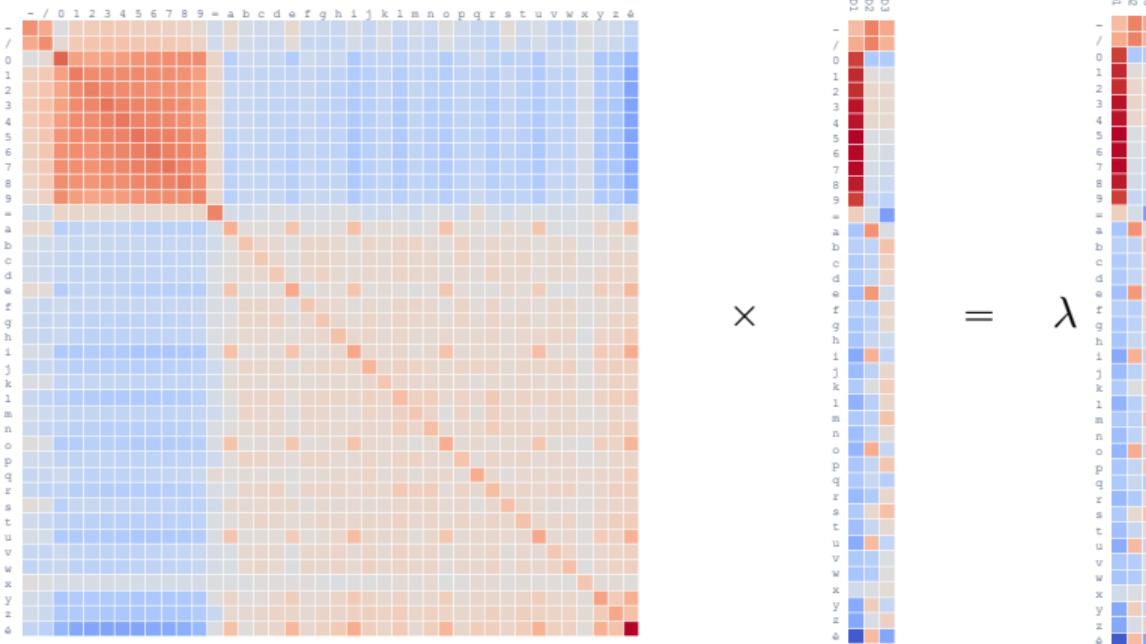
$M_*$



$M_* M^*$

# Vecteurs propres comme points fixes

$$M_* M^* u = \lambda u$$

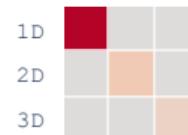


# Traits structuraux

Eigenvectors of  $M_* M^*$ :



Eigenvalues of  $M_* M^*$  and  $M^* M_*$ :



Eigenvectors of  $M^* M_*$ :



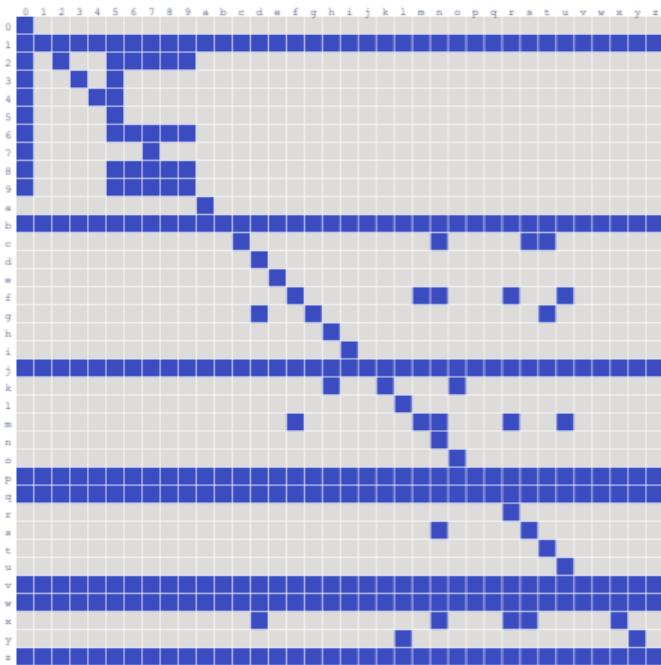
# Mots

|      | -5        | -4         | -3      | -2         | -1      | 0   | 1          | 2           | 3         | 4          | 5        |
|------|-----------|------------|---------|------------|---------|-----|------------|-------------|-----------|------------|----------|
| D 1  | church    | university | field   | house      | centre  | ... | held       | used        | offered   | found      | made     |
| D 2  | use       | leave      | keep    | buy        | meet    | ... | boy        | club        | sun       | uk         | hotel    |
| D 3  | show      | boy        | project | move       | play    | ... | production | size        | interests | activities | nature   |
| D 4  | used      | expected   | made    | considered | allowed | ... | london     | europe      | scotland  | france     | england  |
| D 5  | used      | expected   | food    | water      | england | ... | during     | couple      | under     | series     | lot      |
| D 6  | perhaps   | indeed     | under   | during     | in      | ... | cup        | bit         | series    | couple     | lot      |
| D 7  | difficult | hard       | easy    | necessary  | close   | ... | won        | gave        | started   | saw        | took     |
| D 8  | europe    | scotland   | england | france     | lot     | ... | middle     | want        | needs     | army       | could    |
| D 9  | wish      | tried      | seem    | seemed     | began   | ... | received   | established | won       | published  | produced |
| D 10 | 10        | 15         | 20      | 30         | 3       | ... | from       | on          | black     | into       | through  |



# Points fixes booléens

$$M_i^* M_*^i \textcolor{blue}{d} = d$$



★



?  $\equiv$



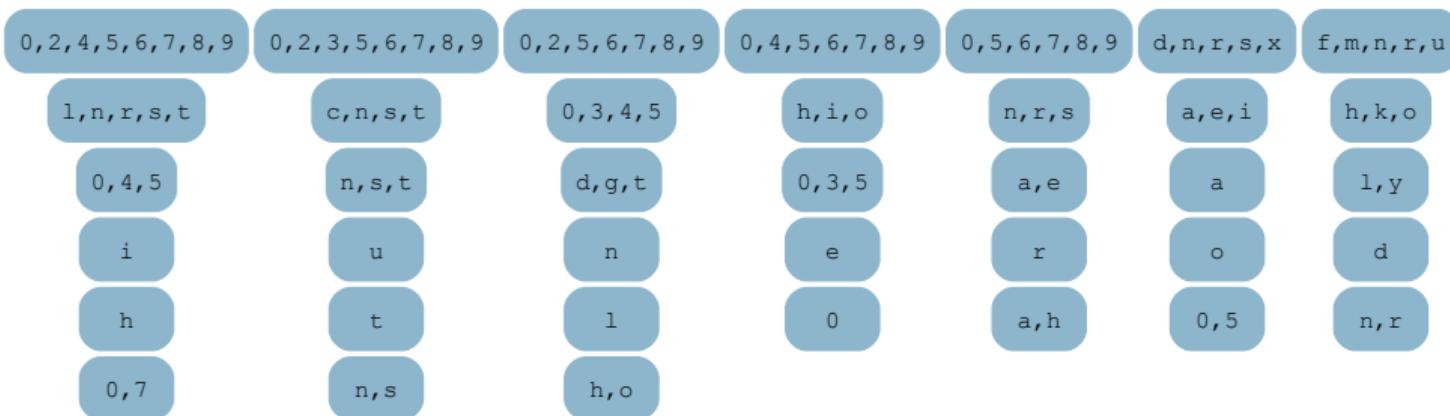
# “Eigensets”

$$\mathcal{M}_*\mathcal{M}^*f = f$$

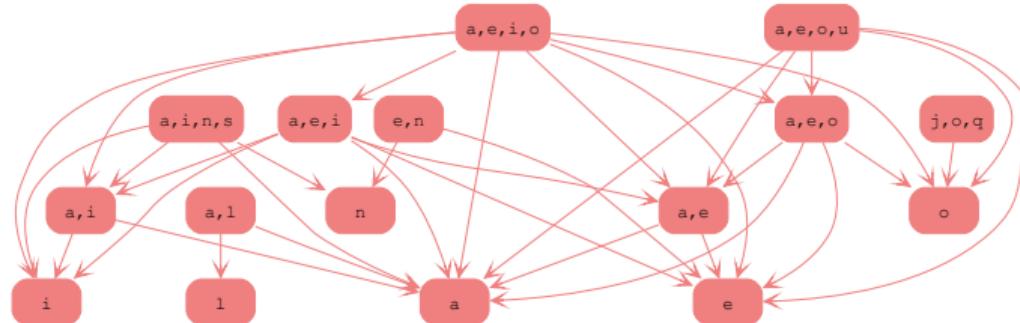
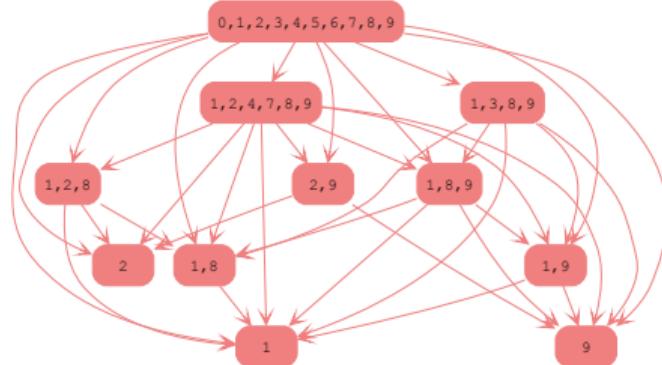
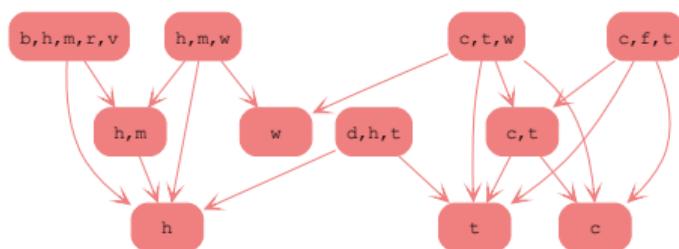
|                       |               |             |           |           |           |           |
|-----------------------|---------------|-------------|-----------|-----------|-----------|-----------|
| $0,1,2,3,4,5,6,7,8,9$ | $1,2,4,7,8,9$ | $b,h,m,r,v$ | $a,e,i,o$ | $a,e,o,u$ | $a,i,n,s$ | $1,3,8,9$ |
| $1,2,8$               | $h,m,w$       | $1,8,9$     | $d,h,t$   | $j,o,q$   | $c,f,t$   | $c,t,w$   |
| $a,e,o$               | $a,e,i$       | $h,m$       | $2,9$     | $a,i$     | $w$       | $1,9$     |
| $1,8$                 | $a,e$         | $l$         | $t$       | $n$       | $c$       | $h$       |
| $2$                   | $i$           | $e$         | $a$       | $o$       | $1$       | $9$       |
| $e,n$                 | $a,l$         | $c,t$       |           |           |           |           |

# “Eigensets”

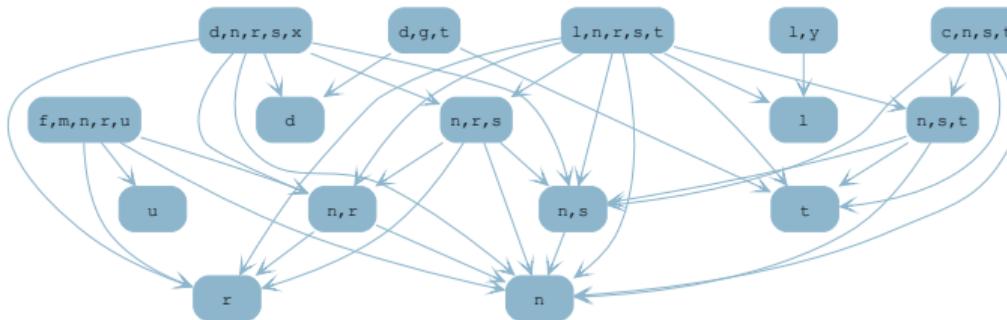
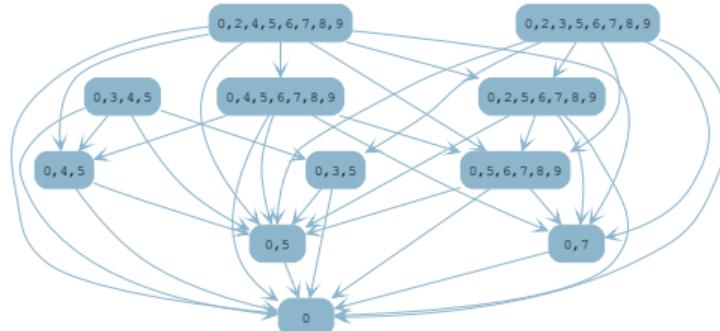
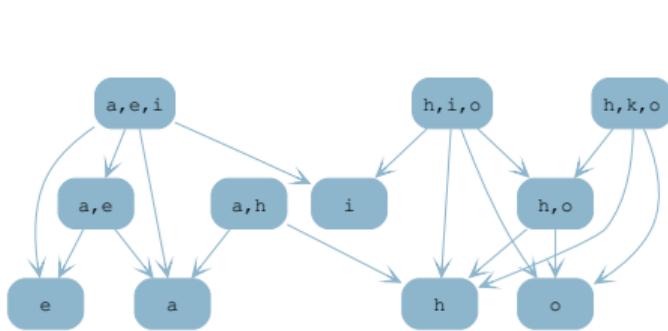
$$M_i^* M_*^i \mathbf{d} = \mathbf{d}$$



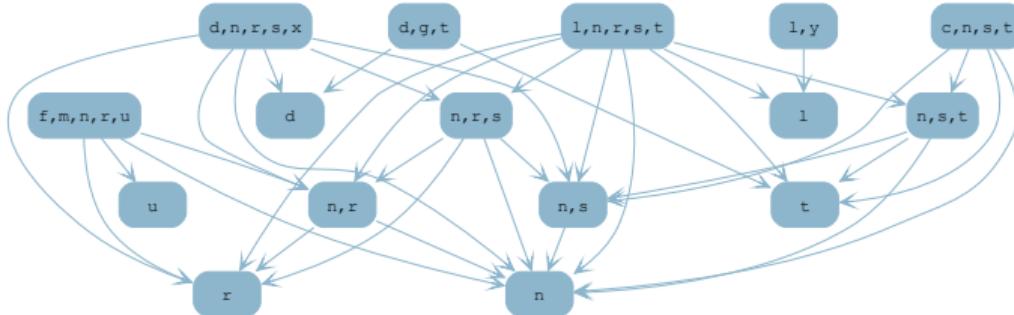
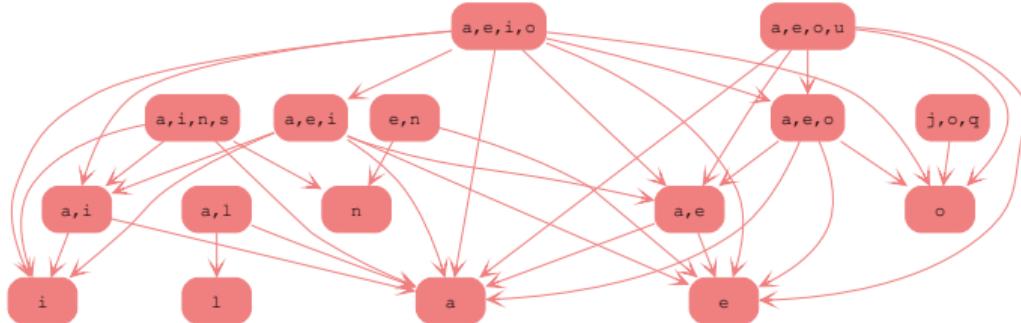
# Quelle Structure?



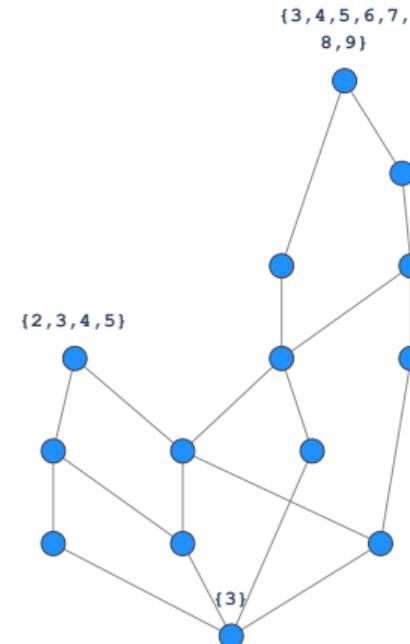
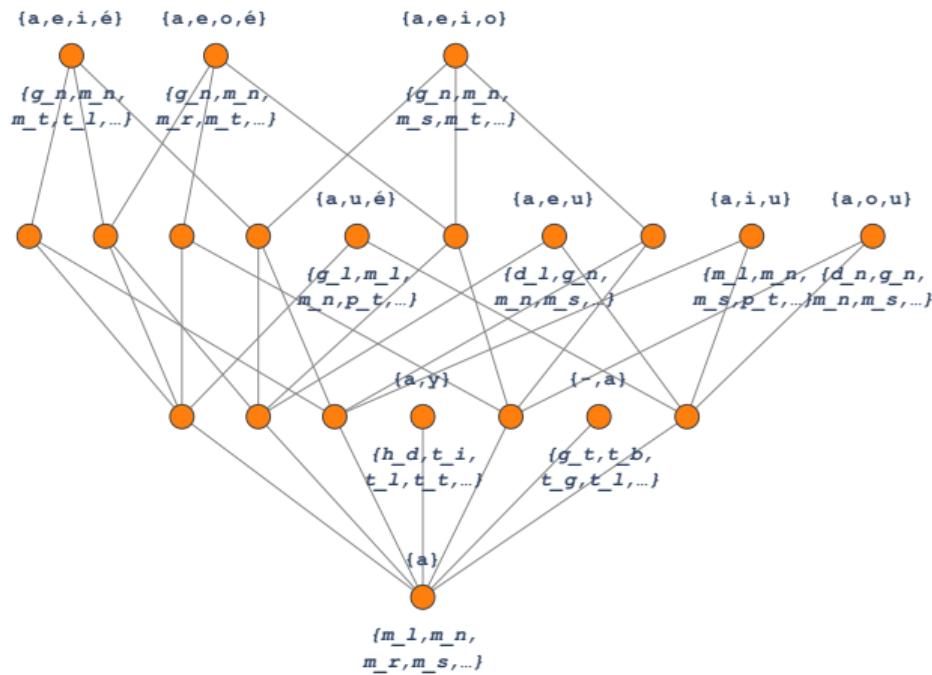
# Quelle Structure?



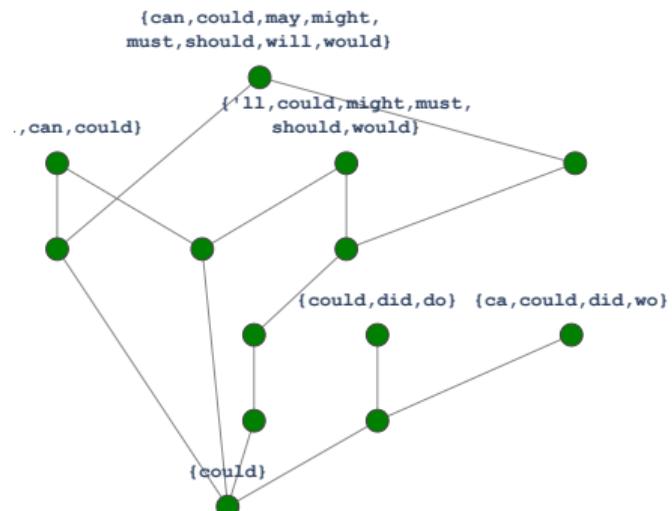
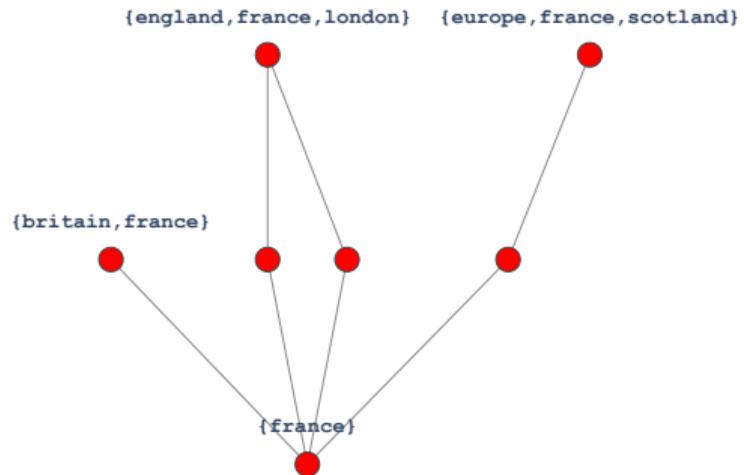
# Quelle Structure?



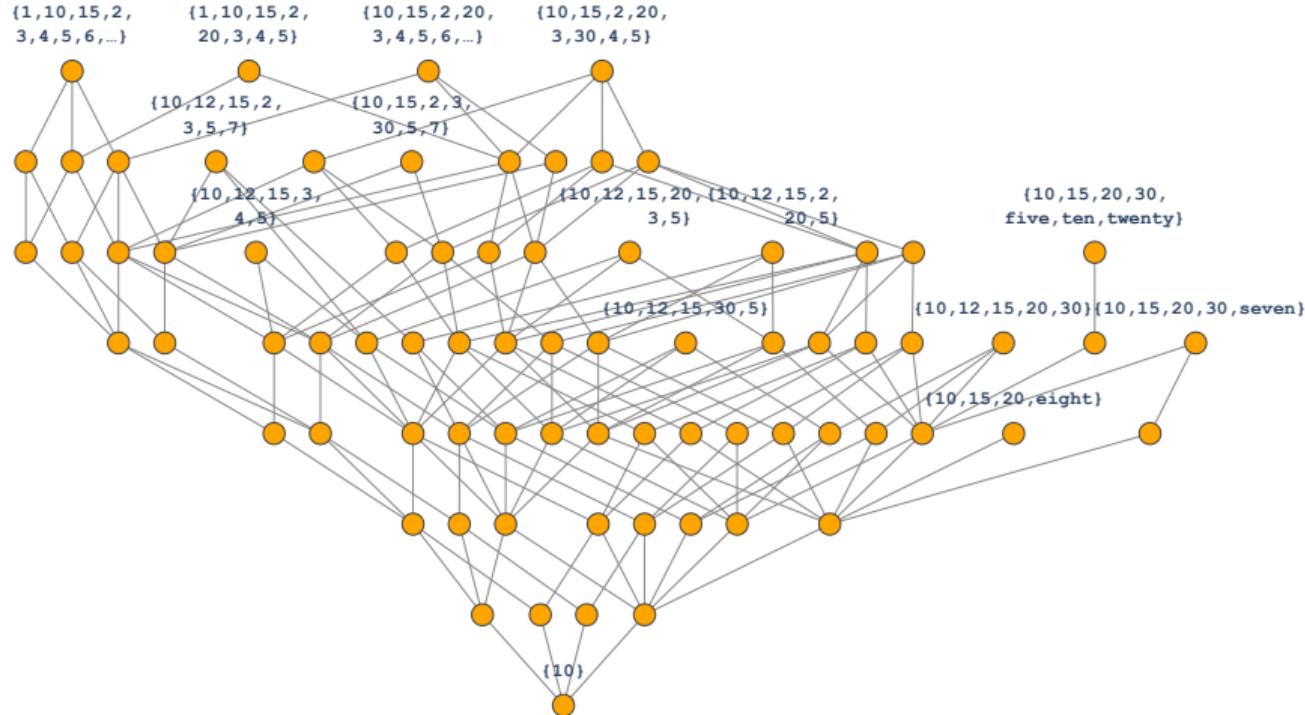
# Concepts formels



# Concepts formels (mots)

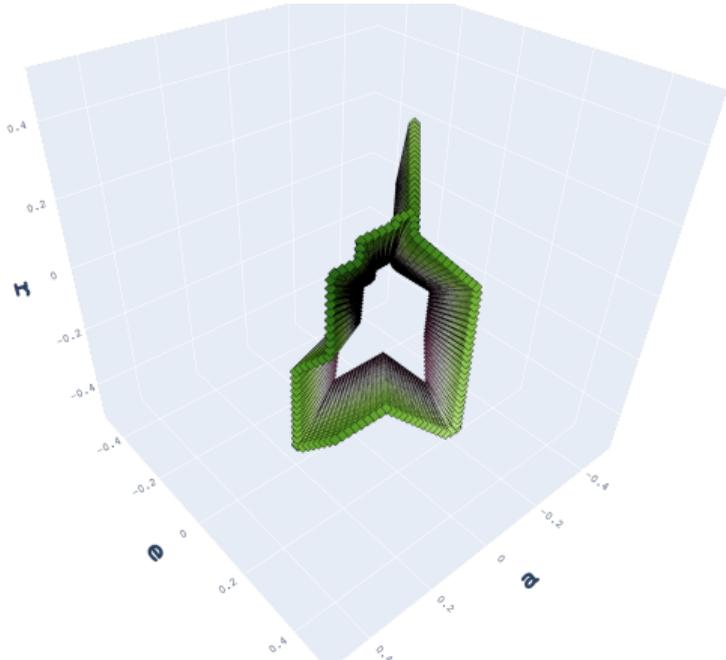
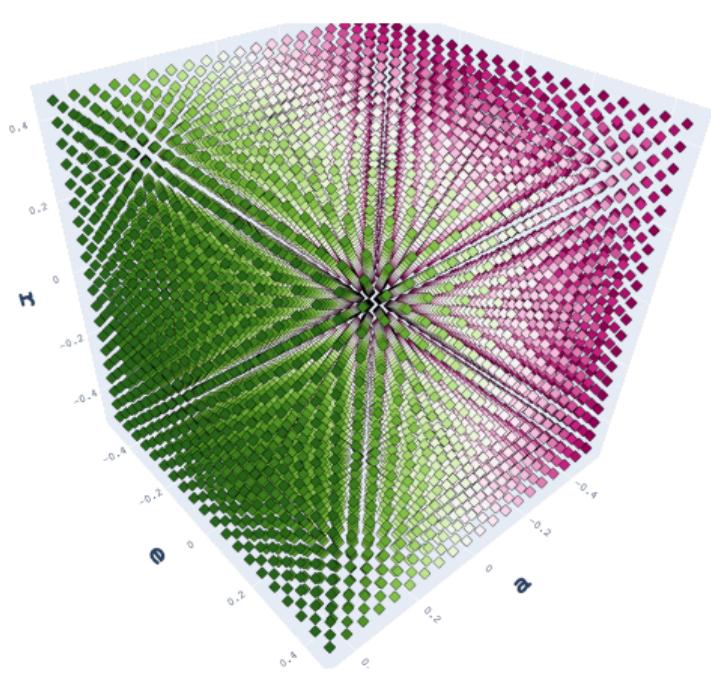


# Concepts formels (mots)

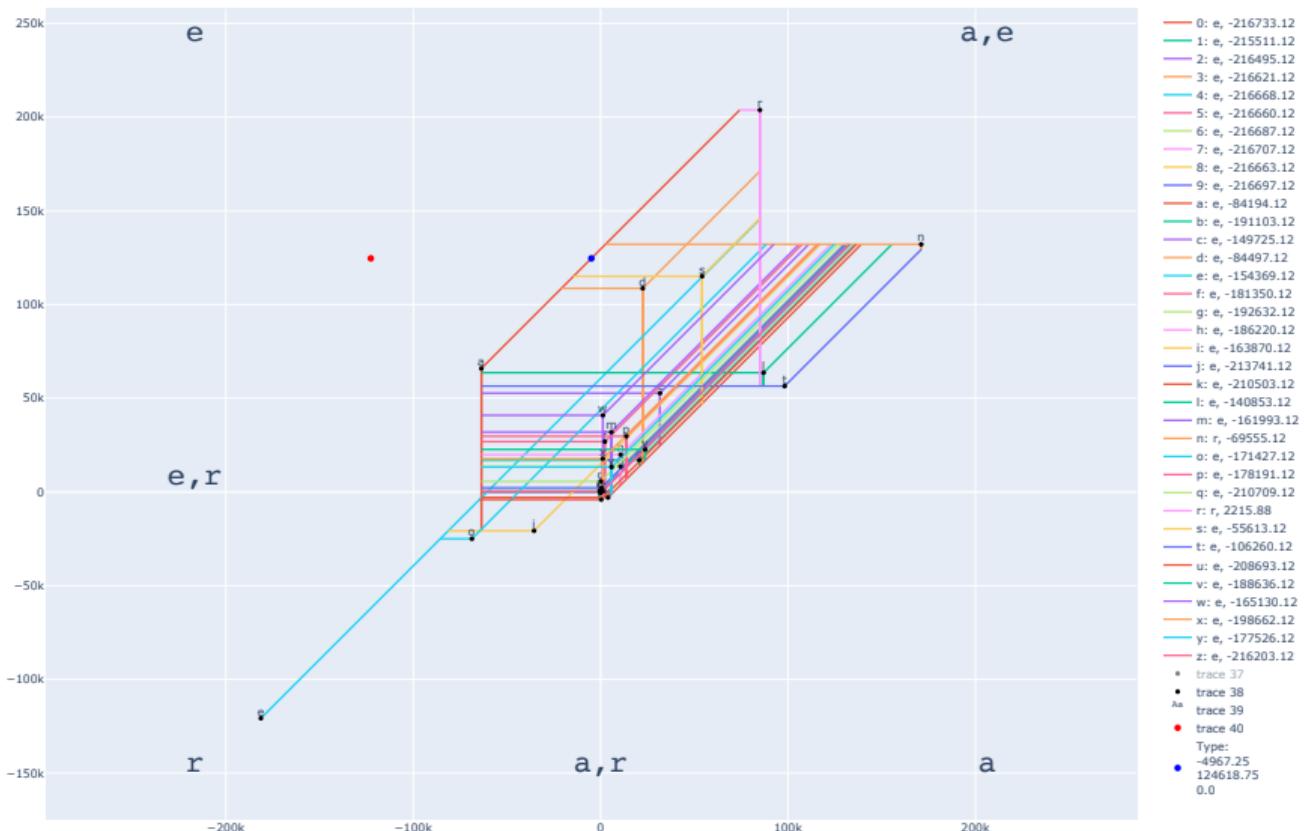


# Noyau (nucleus)

$$\bar{\mathbb{R}}^{\{a,e,r\}} \xrightarrow{\mathcal{M}_*\mathcal{M}^*} \bar{\mathbb{R}}^{\{a,e,r\}}$$



# Structure interne du noyau



# Théorie des types computationnels

## Definition (Polaire/Orthogonal - Girard, 2006)

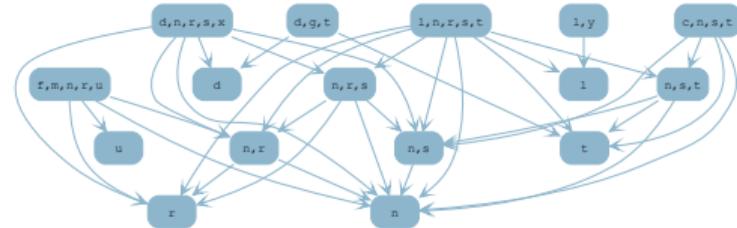
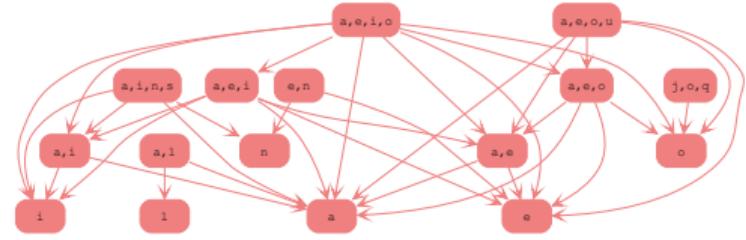
[É]tant donnée une fonction binaire

$a, b \rightsquigarrow \langle a|b \rangle : A \times B \rightarrow C$  et un sous-ensemble  $P \subset C$  (le « pôle »), on peut définir le *polaire*  $X^\perp \subset B$  d'un sous-ensemble  $X \subset A$  (resp.  $Y^\perp \subset A$  d'un sous-ensemble  $Y \subset B$ ) par :

$$X^\perp := \{y \in B : \forall x \in X, \langle a|b \rangle \in P\}$$

$$Y^\perp := \{x \in A : \forall y \in Y, \langle a|b \rangle \in P\}$$

- ◊ L'application « polaire » est décroissante:  $X \subset X' \Rightarrow X'^\perp \subset X^\perp$ .
- ◊ L'ensemble  $\text{Pol}(A) \subset \mathcal{P}(A)$  des ensembles *polaires*, i.e., de la forme  $Y^\perp$ , est stable par intersections arbitraires. En particulier,  $A$  est polaire et  $X^{\perp\perp}$  est le plus petit ensemble polaire contenant  $X$ .
- ◊ En conséquence,  $X^{\perp\perp\perp} = X^\perp$ .



# Théorie des types computationnels

## Definition (Polaire/Orthogonal - Girard, 2006)

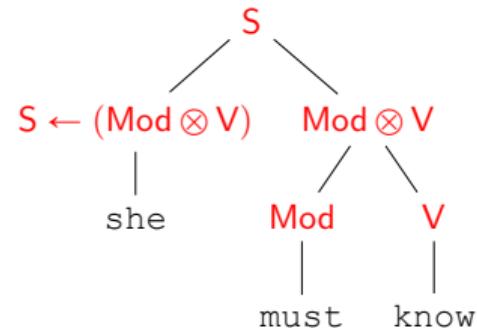
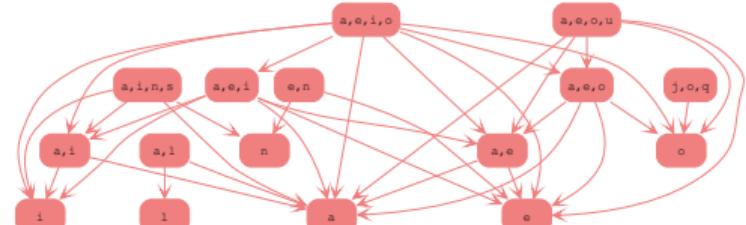
[É]tant donnée une fonction binaire

$a, b \rightsquigarrow \langle a|b \rangle : A \times B \rightarrow C$  et un sous-ensemble  $P \subset C$  (le « pôle »), on peut définir le *polaire*  $X^\perp \subset B$  d'un sous-ensemble  $X \subset A$  (resp.  $Y^\perp \subset A$  d'un sous-ensemble  $Y \subset B$ ) par :

$$X^\perp := \{y \in B : \forall x \in X, \langle a|b \rangle \in P\}$$

$$Y^\perp := \{x \in A : \forall y \in Y, \langle a|b \rangle \in P\}$$

- ◊ L'application « polaire » est décroissante:  $X \subset X' \Rightarrow X'^\perp \subset X^\perp$ .
- ◊ L'ensemble  $\text{Pol}(A) \subset \mathcal{P}(A)$  des ensembles *polaires*, i.e., de la forme  $Y^\perp$ , est stable par intersections arbitraires. En particulier,  $A$  est polaire et  $X^{\perp\perp}$  est le plus petit ensemble polaire contenant  $X$ .
- ◊ En conséquence,  $X^{\perp\perp\perp} = X^\perp$ .



(Gastaldi and Pellissier, 2021)

# Matrice et analogie

a = your  
c = my

w = apartment  
x = house  
y = chair  
z = stool

your : house  
my : apartment

|     | ... | w | x | y | z | ... |
|-----|-----|---|---|---|---|-----|
| ... | ... | 0 | 0 | 0 | 0 | ... |
| a   | ... | 0 | 1 | 1 | 0 | ... |
| b   | ... | 0 | 0 | 1 | 1 | ... |
| c   | ... | 1 | 0 | 0 | 1 | ... |
| ... | ... | 0 | 0 | 0 | 0 | ... |

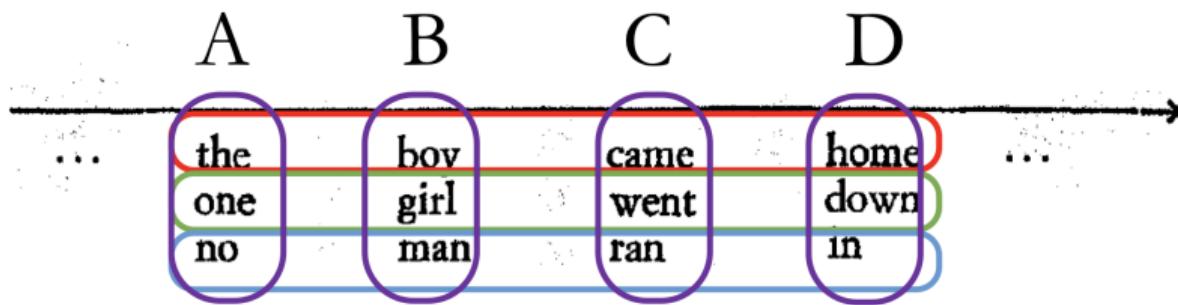
## Matrice et analogie

|     | 1    | 2    | 3    | 4    |     |
|-----|------|------|------|------|-----|
| ... | the  | boy  | came | home | ... |
| one | girl | went | down |      |     |
| no  | man  | ran  | in   |      |     |

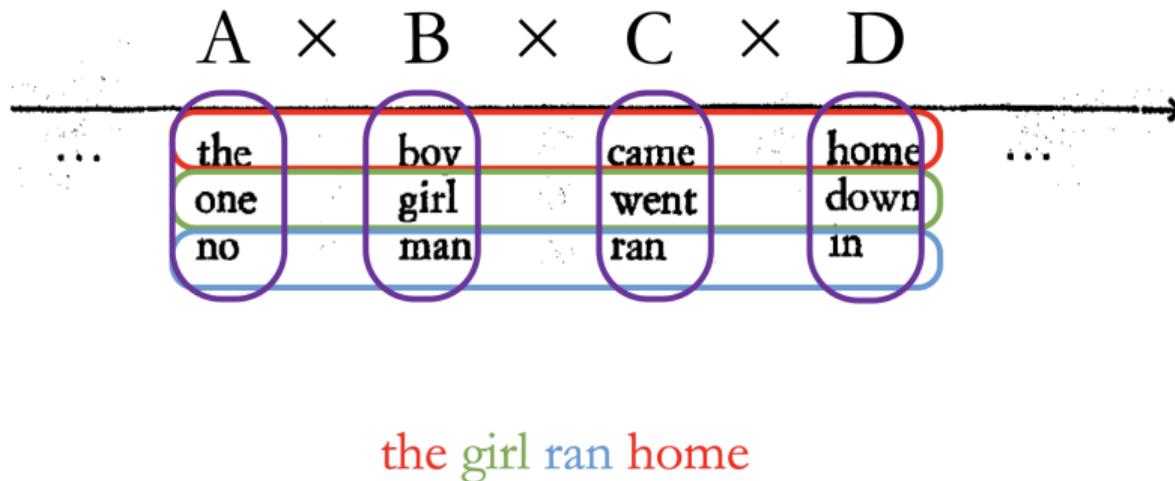
# Matrice et analogie

| 1   | 2    | 3    | 4    |      |
|-----|------|------|------|------|
| ... | the  | bov  | came | home |
| one | girl | went | down |      |
| no  | man  | ran  | in   |      |

# Matrice et analogie



# Matrice et analogie

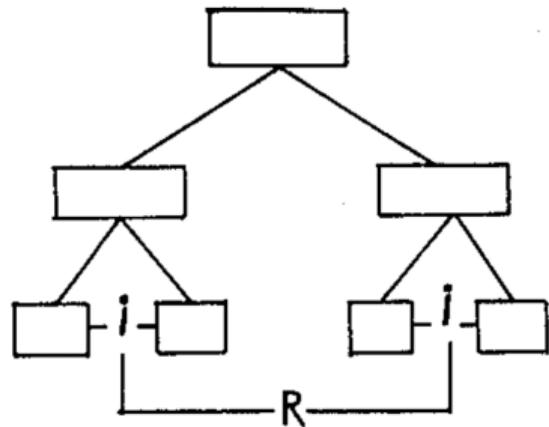


Une **sémiotique** [...] est une hiérarchie dont chacune des composantes admet une analyse ultérieure en classes définies par relation mutuelle, de telle sorte que chacune de ces classes admette une analyse en dérivés définis par mutation mutuelle.

(Hjelmslev, 1975, Df. 24)

Une **mutation** [...] est une fonction existant entre des dérivés du premier degré d'une seule et même classe, une fonction qui a une relation à une fonction entre d'autres dérivés de premier degré d'une seule et même classe et appartenant au même rang.

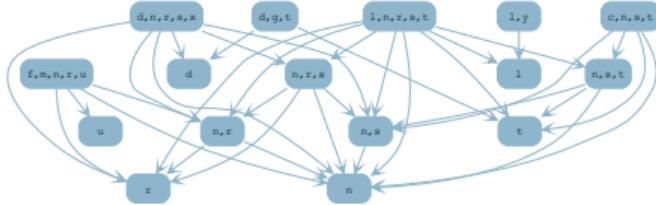
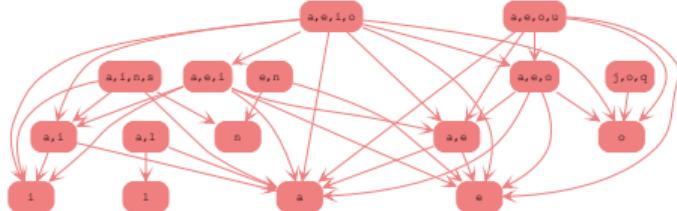
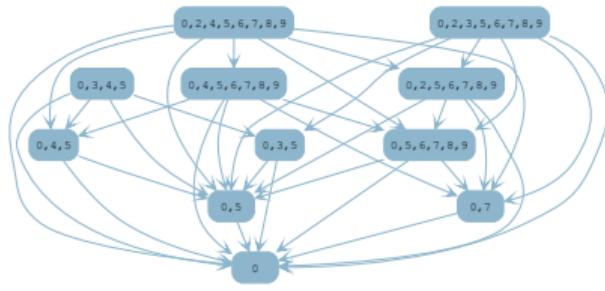
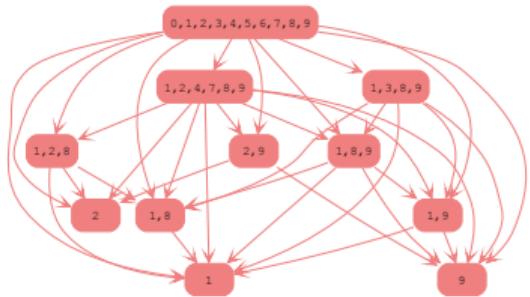
(Hjelmslev, 1975, Df. 23)



## Syntagmatique et Texte (Vecteurs)



# Syntagmatique et Texte (Noyau/Types)



# Paradigmatique et Langue (Vecteurs)

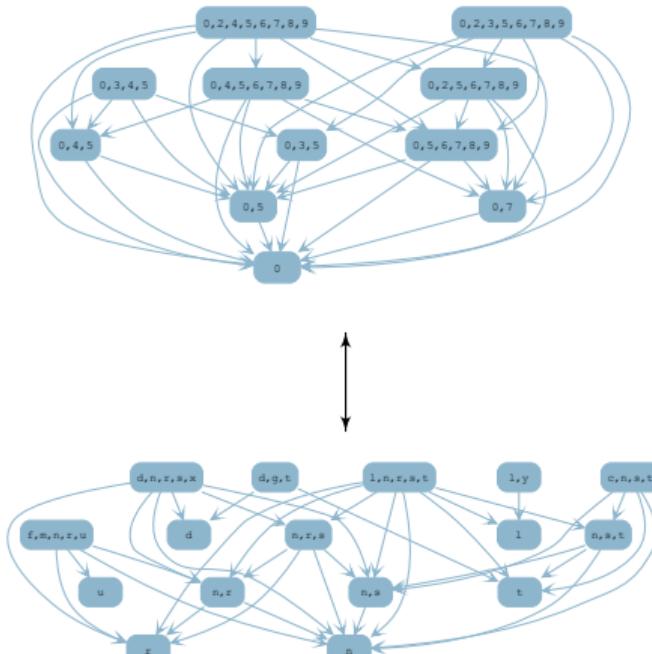
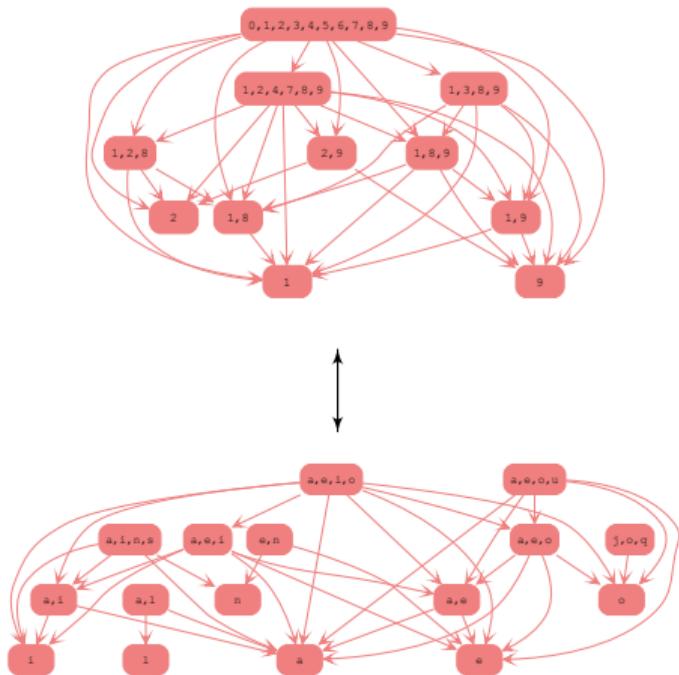
|     |    |    |    |    |    |    |    |    |    |     |
|-----|----|----|----|----|----|----|----|----|----|-----|
| -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | ... |
| D 1 | é  | z  | i  | y  | u  | l  | o  | r  | j  | n   |
| ... | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10  |
|     | 0  | 9  | 2  | 1  | 8  | 4  | 3  | 7  | 6  | 5   |

|     |     |     |      |      |     |      |      |      |      |     |
|-----|-----|-----|------|------|-----|------|------|------|------|-----|
| -10 | -9  | -8  | -7   | -6   | -5  | -4   | -3   | -2   | -1   | ... |
| D 1 | x_é | l_é | n_é  | f_é  | s_é | e_é  | i_é  | u_é  | w_q  | z_u |
| ... | 1   | 2   | 3    | 4    | 5   | 6    | 7    | 8    | 9    | 10  |
|     | =_9 | =_6 | 7_-9 | 9_-9 | =_5 | 9_-5 | 9_-7 | 9_-6 | 9_-8 | 9_0 |

|     |   |   |   |   |   |     |     |     |     |     |
|-----|---|---|---|---|---|-----|-----|-----|-----|-----|
| 0   | r | w | v | f | l | j   | m   | g   | n   | ... |
| D 2 | 3 | y | u | é | i | o   | e   | a   | -   | /   |
|     | z | p | f | m | g | t_g | é_m | z_m | z_g | z_q |

|     |     |     |     |     |     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0_é | 5_é | 8_é | -_é | 2_é | u_é | =_o | 9_é | 4_é | 7_é | ... |
| D 2 | d_m | z_p | z_f | k_m | r_g | t_g | é_m | z_m | z_g | z_q |
|     | z   | p   | f   | m   | g   | t_g | é_m | z_m | z_g | z_q |

# Paradigmatique et Langue (Noyau/Types)



# Illustration du contenu formel

(Gastaldi and Pellissier, 2021)

## Characteristic Content

```
{cat, dog, spider,  
gavagai}
```

Atomic Type

## Syntactic Content

"the gavagai is on the  
mat"

Profunctor Nucleus

## Informational Content

```
{cat:0.059%,  
dog:0.012%,  
spider:0.009%  
gavagai:0.000%}
```

Probability Distribution