APPLICATION OF THE GENERALIZED INTERVAL-VALUED SUGENO INTEGRAL IN BRAIN COMPUTER INTERFACES AND SOCIAL NETWORKS

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OUTLINE

Some notions about the Sugeno integral

Our proposed FG-IV Sugeno integral

Application to a Brain Computer Interface:

- How we generate the intervals
- How we Aggregate them

Application to social networks:

- How we construct IV-relationships between actors.
- How to interpret the aggregated value of those relationships.

SUGENO INTEGRAL

Discrete Sugeno integral. Let $m: 2^N \to [0,1]$ be a fuzzy measure. The discrete Sugeno integral of $\boldsymbol{x} = (x_1, .., x_n) \in [0,1]^n$ with respect to m is defined as a function $S_m: [0,1]^n \to [0,1]$ given by:

$$S_m(x) = \max\{\min\left(x_{\sigma(i)}, m(A_i)\right) \mid i = 1, .., n\}$$

FG-SUGENO INTEGRAL

- We can generalize the discrete Sugeno integral using **a n-ary function G** instead of the máximum and a **bi-variant F** function

FG-Sugeno integral. Let $m: 2^N \to [0,1]$ be a fuzzy measure. The discrete Sugeno integral of $\boldsymbol{x} = (x_1, .., x_n) \in [0,1]^n$ with respect to m is defined as a function $S_m: [0,1]^n \to [0,1]$ given by:

$$S_m(x) = G\{F\left(x_{\sigma(i)}, m(A_i)\right) \mid i = 1, .., n\}$$

Francesco Bardozzo, Borja De La Osa, Ľubomíra Horanská, Javier Fumanal-Idocin, Mattia delli Priscoli, Luigi Troiano, Roberto Tagliaferri, Javier Fernandez, Humberto Bustince (2021). Sugeno integral generalization applied to improve adaptive image binarization. *Information Fusion*, *68*, 37-45.

IV-SUGENO INTEGRAL

We can use a λ preference to construct a IV-Sugeno integral.

IV-Sugeno with λ-preference. Let $m: 2^N \rightarrow [0,1]$ be a fuzzy measure. The Interval Sugeno Integral with preference λ is defined as:

$$S_{\lambda;\,\mu}(x) = \ sup_{\leq\lambda}\{[\mu(L) \wedge min_{i\in L}\{x_l(i)\}, \mu(U) \wedge min_{i\in \mathrm{U}}\{x_u(i)]|\ L\ \subseteq U, min_{i\in L}\{x_l(i)\} \leq min_{i\in U}\{x_u(i)\}\}$$

Pu, X., Mesiar, R., Yager, R. R., & Jin, L. (2019). Interval Sugeno Integral With Preference. *IEEE Transactions on Fuzzy Systems*, *28*(3), 597-601.

GENERALIZED FG-IV SUGENO

- **FG-IV Sugeno integral:**

$\preccurlyeq$ *be an admissible order on* $L([0,1])$

A **bi-variant** function $F: L([0,1]) \times L([0,1]) \to L([0,1])$

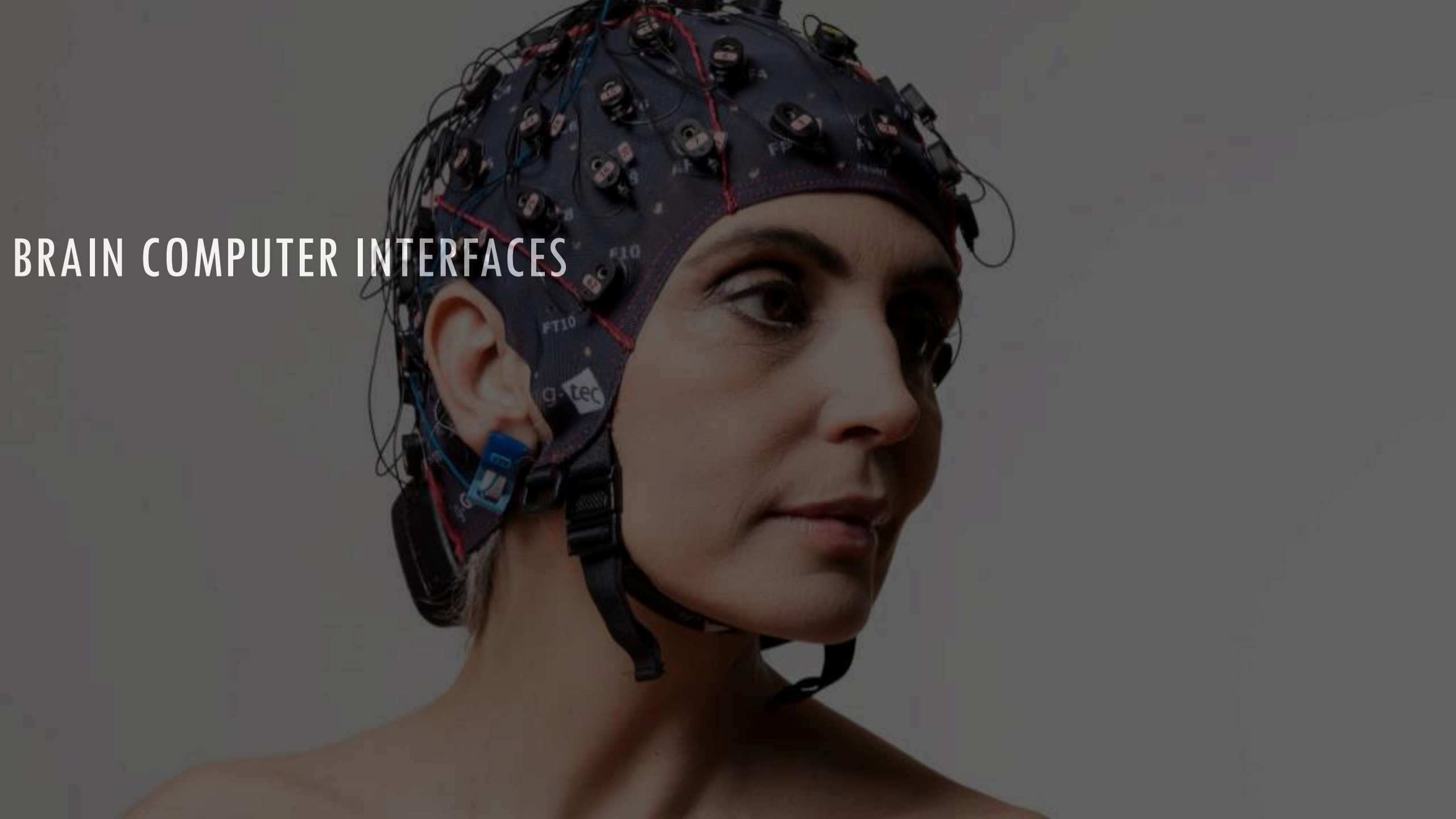
Interval-valued inputs: $X_1, \dots, X_n \in L([0,1])$

A **n-ary** function $G: (L[0,1])^n \to L([0,1])$

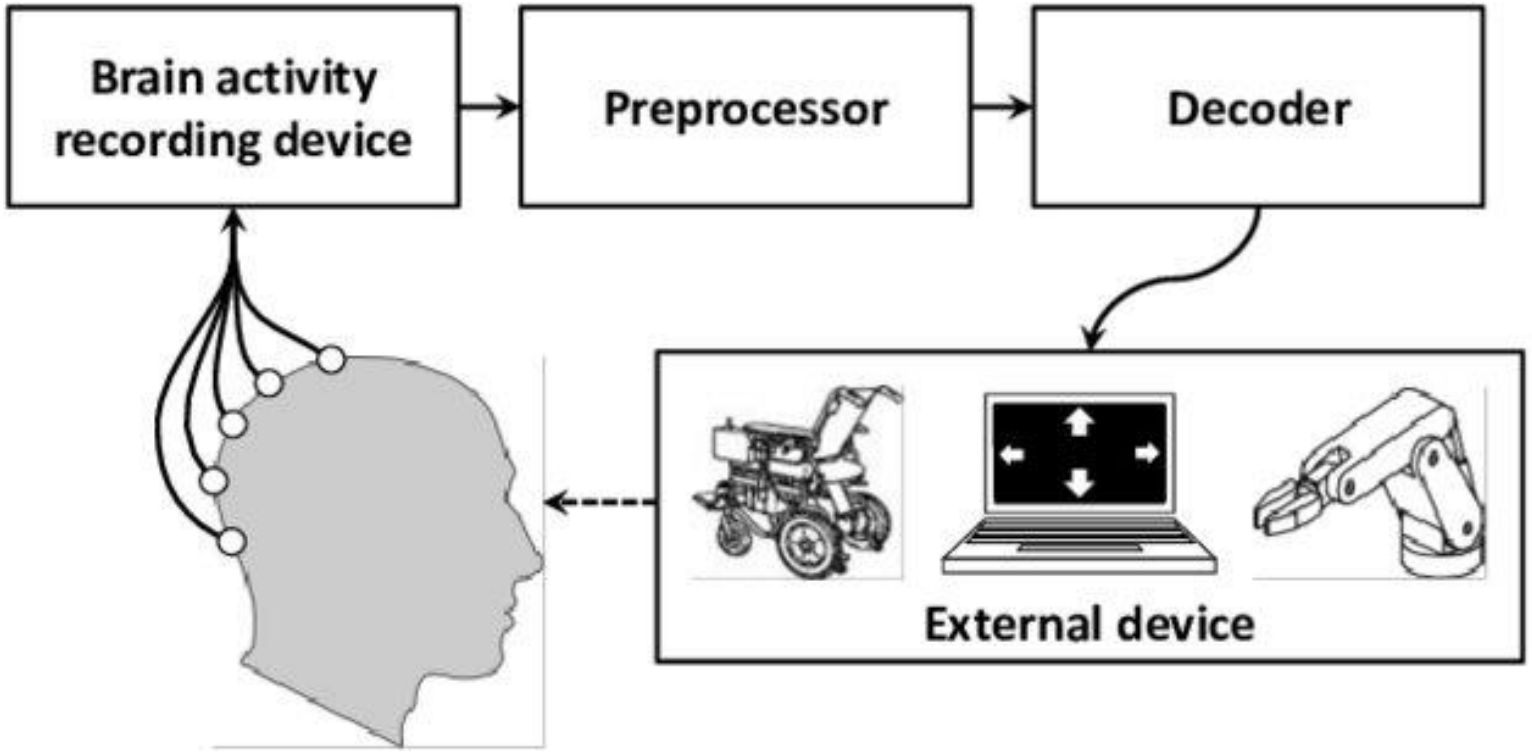
$$S_m^{F,G}(X_1, \dots, X_n) = G(F\left(X_{\sigma(1)}, m\left(E_{\sigma(1)}\right)\right), \dots, F\left(X_{\sigma(n)}, m\left(E_{\sigma(n)}\right)\right))$$

where $E\_\sigma_j(i) = \{\sigma_j(i), \dots, \sigma_j(n)\}$ for $j \in \{1,2\}$

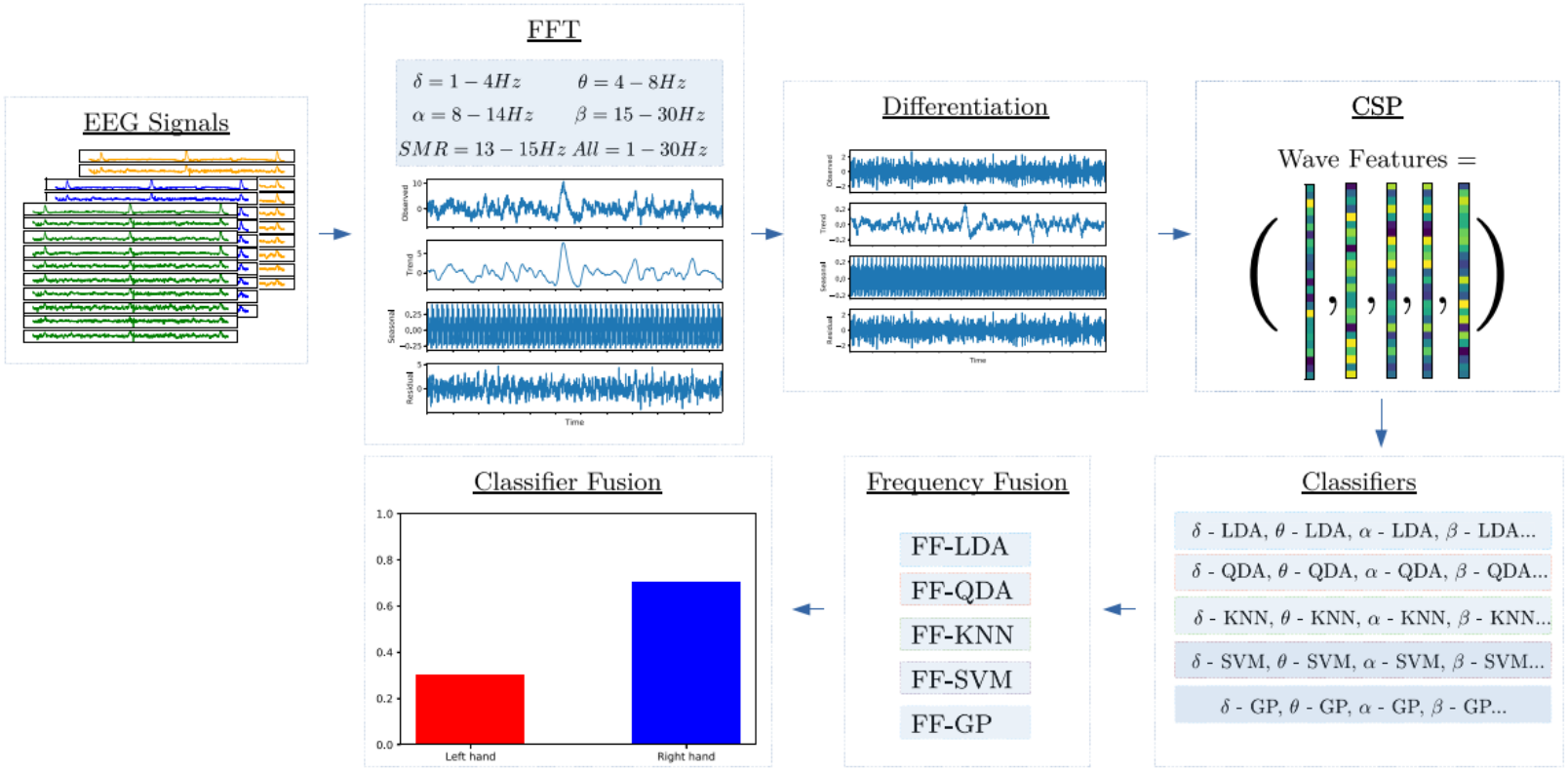
BRAIN COMPUTER INTERFACES



BASIC SCHEME

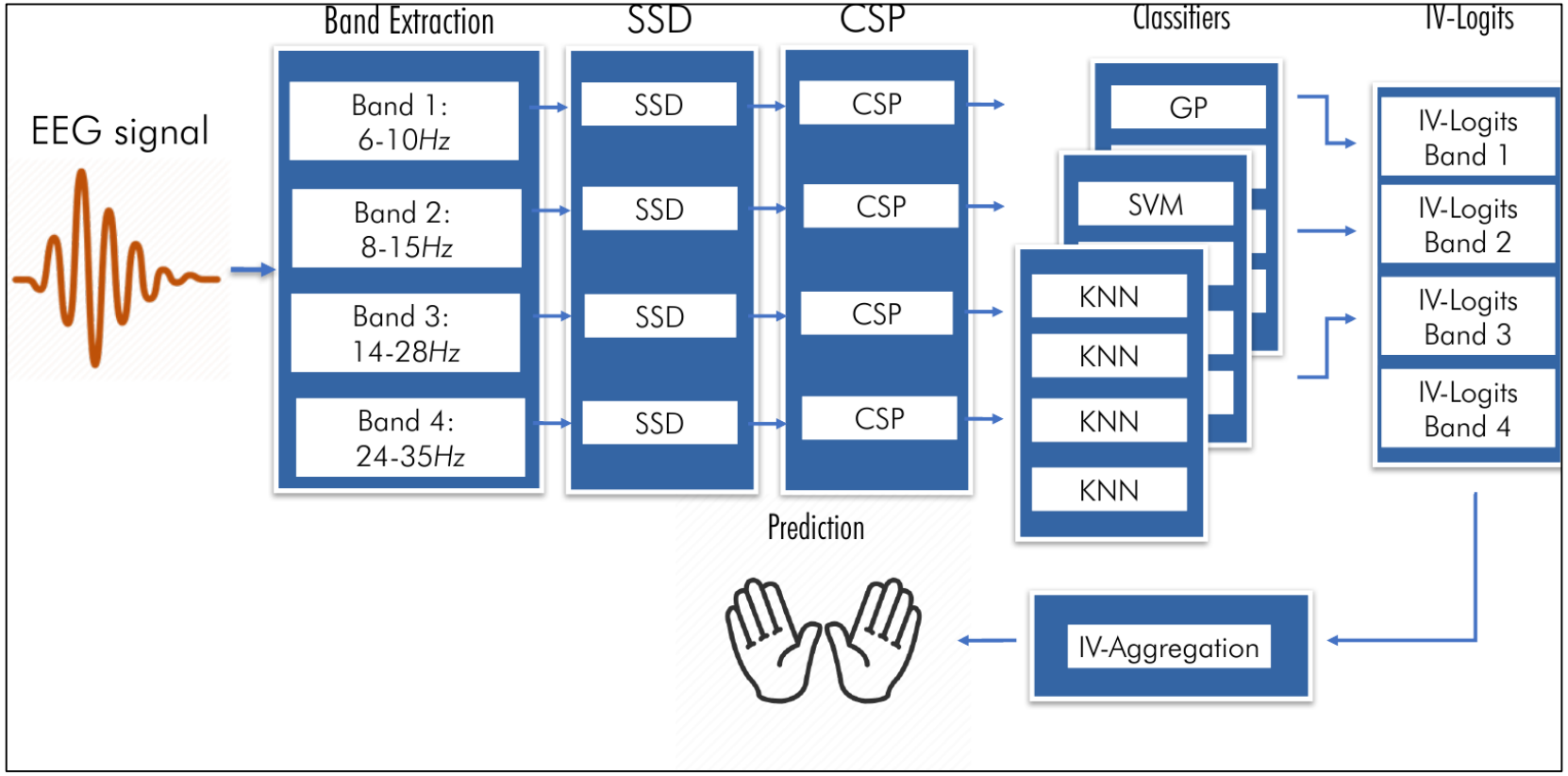


BCI FRAMEWORK

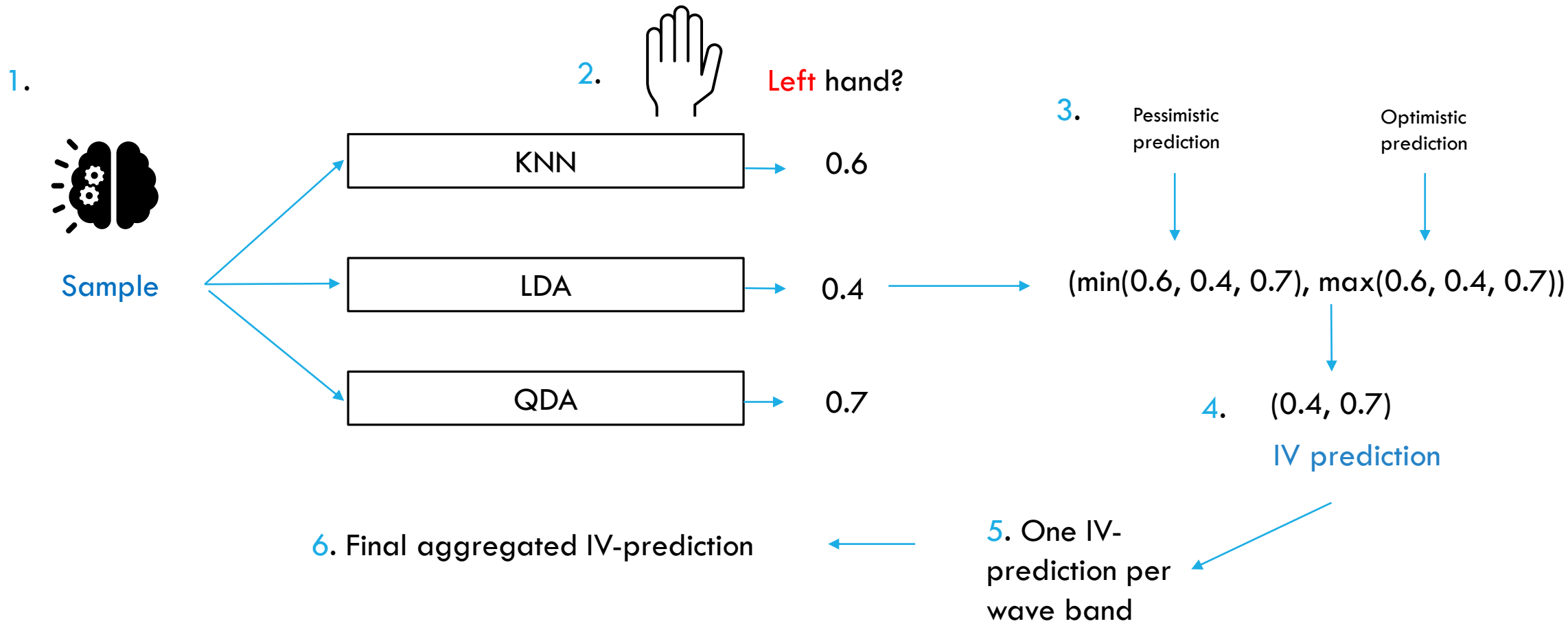


Fumanal-Idocin, J., Wang, Y. K., Lin, C. T., Fernández, J., Sanz, J. A., & Bustince, H. (2021). Motor-Imagery-Based Brain-Computer Interface Using Signal Derivation and Aggregation Functions. *IEEE Transactions on Cybernetics*.

OUR FRAMEWORK



IV-GENERATION IN OUR FRAMEWORK



DATASET AND TESTS

1. Clinical Brain–Computer Interface Challenge 2020
    1. Data obtained from different pacients with strokes.
    2. Left/Right hand Motor Imagery movement detection.

10 subjects - 40 trials

Left

Right

Chowdhury, A., & Andreu-Perez, J. (2021). Clinical Brain-Computer Interface Challenge 2020 (CBCIC at WCCI2020): Overview, methods and results. *IEEE Transactions on Medical Robotics and Bionics*.

RESULTS FOR THE CBCIC DATASET

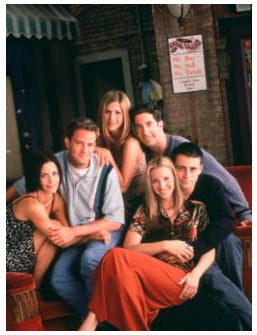
$$G(X_1, \ldots, X_n) = \frac{1}{n} \sum_{i=1}^{n} X_i,\ F(X, Y) = X^2 Y + X(1 - Y);$$

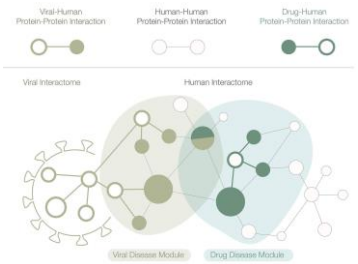
Framework	Accuracy	F1-Score
IV-Sugeno	$\mathbf{0.8175 \pm 0.1342}$	$\mathbf{0.8149 \pm 0.1366}$
EEG Net	0.6562 ± 0.1232	0.5933 ± 0.1712
Shallow Net	0.7453 ± 0.13289	0.7342 ± 0.1489
Deep Net	0.5331 ± 0.1356	0.4218 ± 0.1282
Multiscale CSP	0.7956 ± 0.1144	0.7911 ± 0.1175

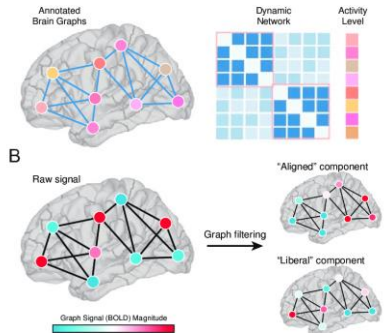
1. V. J. Lawhern, A. J. Solon, N. R. Waytowich, S. M. Gordon, C. P. Hung, B. J. Lance, Eegnet: a compact convolutional neural network for eeg-based brain–computer interfaces, Journal of Neural Engineering 15 (5) (2018).
2. S. R. Tibor, S. J. Tobias, F. L. D. Josef, G. Martin, E. Katharina, T. Michael, H. Frank, B. Wolfram, B. Tonio, Deep learning with convolutional neural networks for eeg decoding and visualization, Human Brain Mapping 38 (11) (2017) 5391–5420.
3. M. Hersche, T. Rellstab, P. D. Schiavone, L. Cavigelli, L. Benini, A. Rahimi, Fast and accurate multiclass inference for mi-bcis using large multiscale temporal and spectral features, in: 2018 26th European Signal Processing Conference (EUSIPCO), 2018, pp. 1690–1694.

SOCIAL NETWORKS

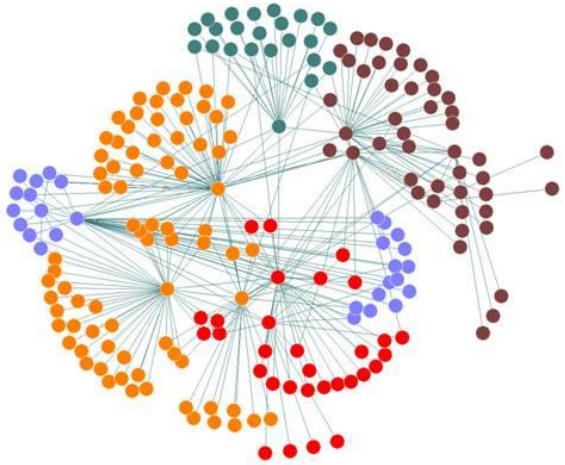
SOCIAL NETWORK ANALYSIS







Real world interactions



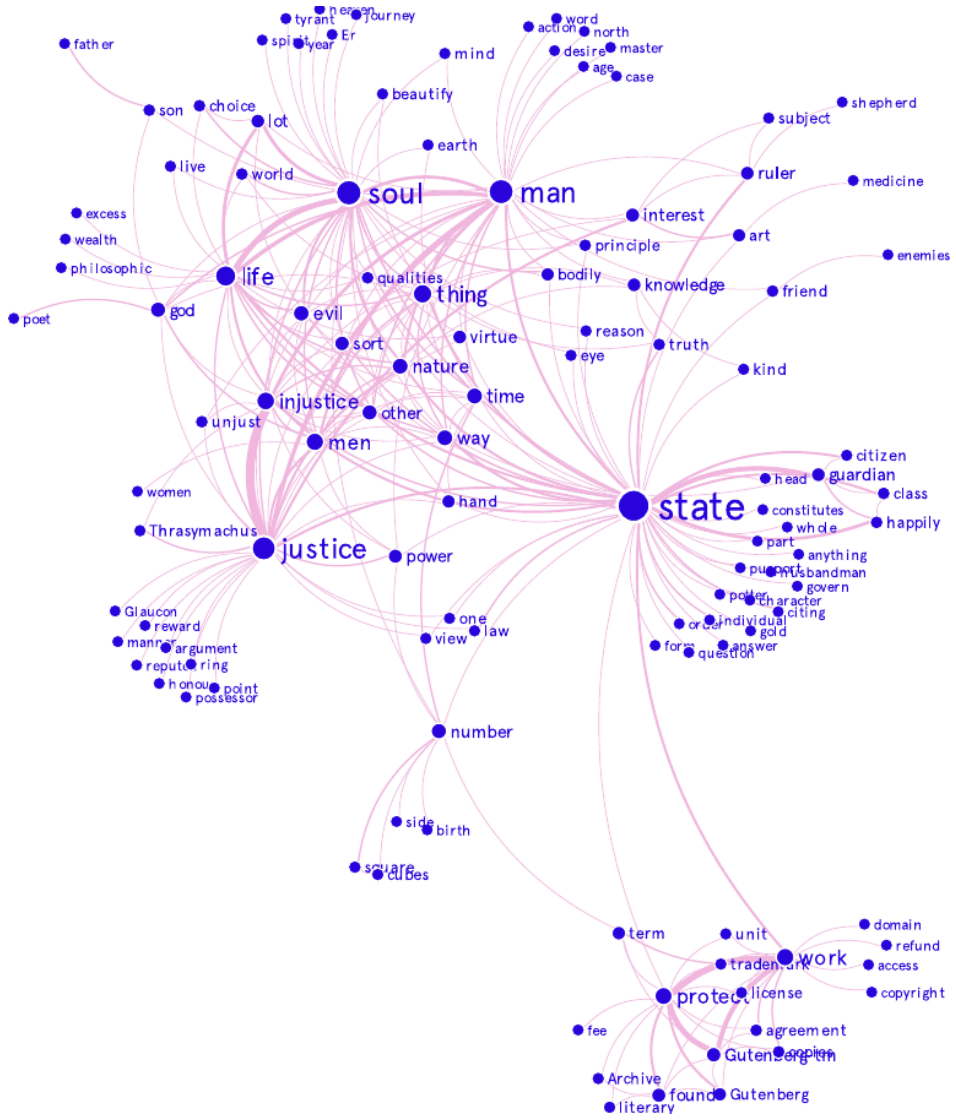
Modelization

Information/
Pattern Discovery

ADJACENCY NETWORKS

Plato's *Republic* Adjacency network:

Number of times each word appear "together"

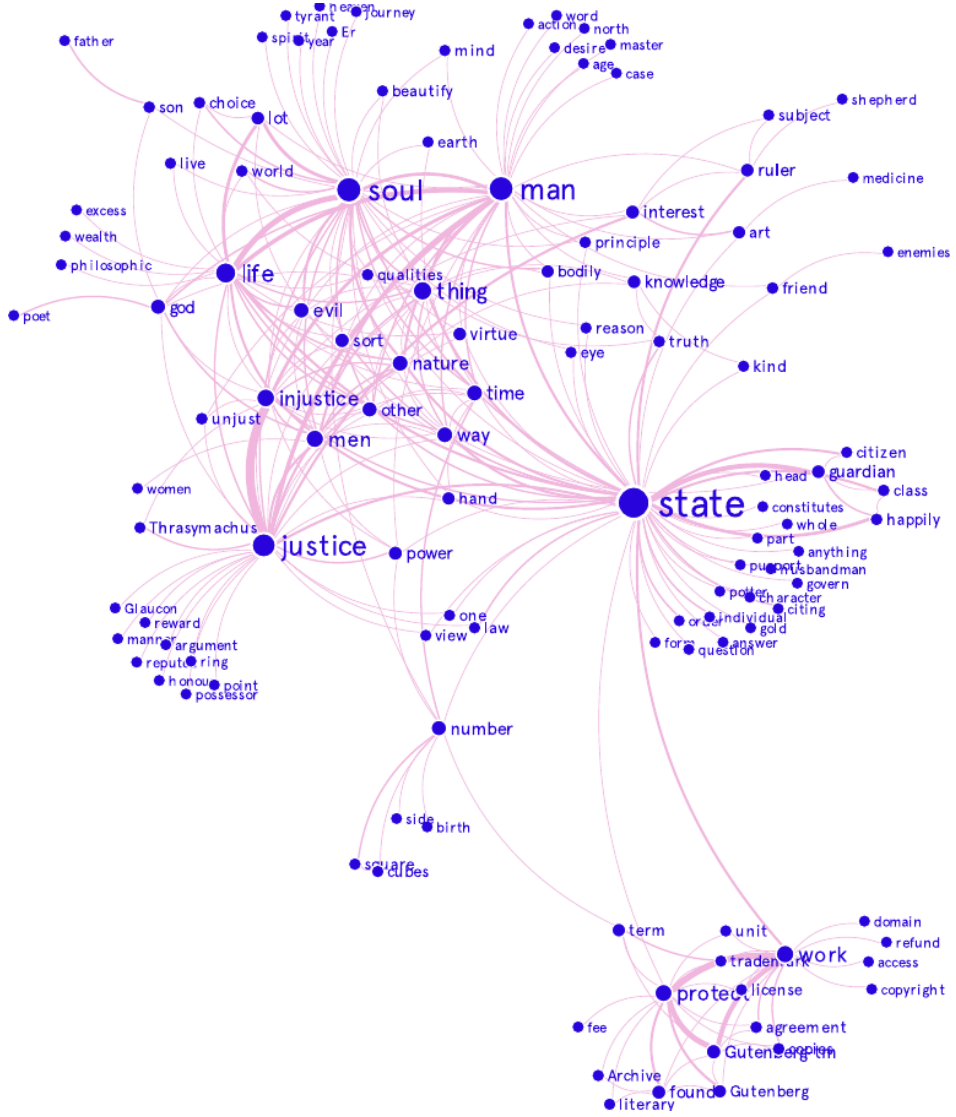


ADJACENCY NETWORKS

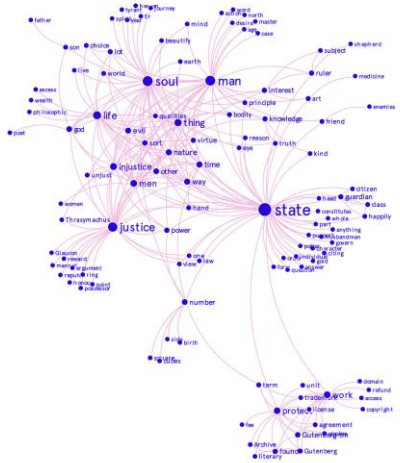
Plato's *Republic* Adjacency network:

Number of times each word appear "together"

Other criteria is possible?

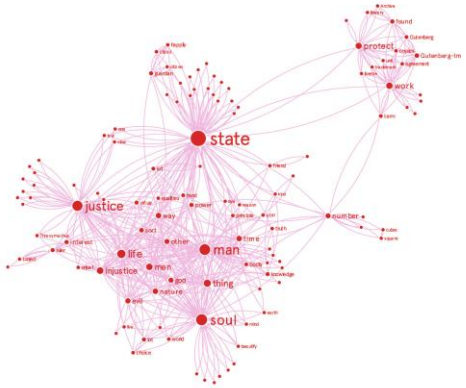


Original:



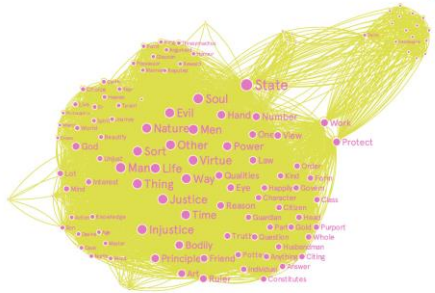
(a)

Importance of each relationship:



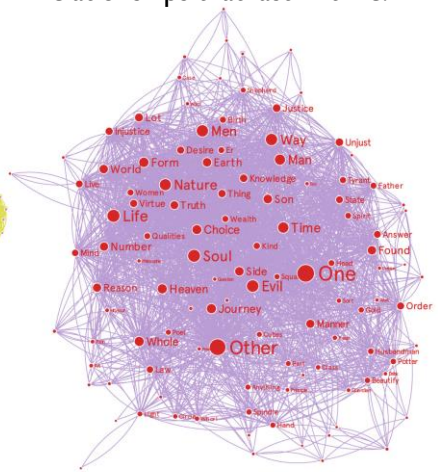
(b)

Common friends:



(c)

Relationships that last in time:



(d)

Similar structural properties:

(e)

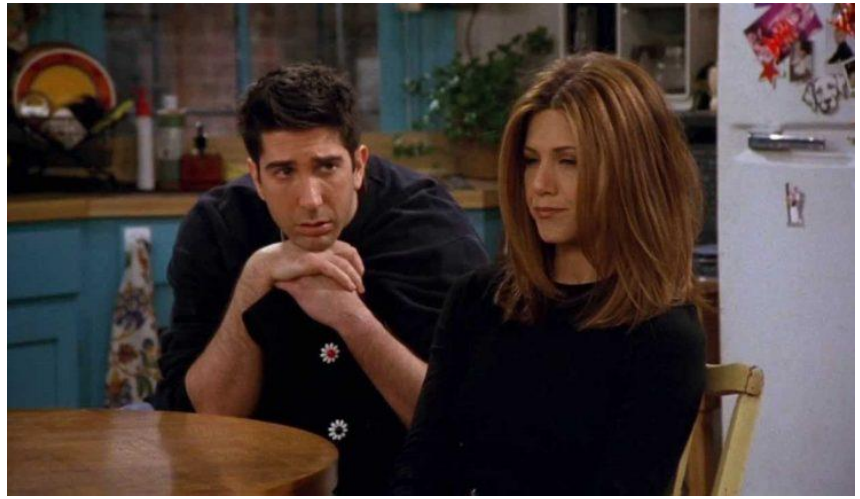
(f)

High affinities between social groups:

Fumanal-Idocin, J., Alonso-Betanzos, A., Cordón, O., Bustince, H., & Minárová, M. (2020). Community detection and social network analysis based on the Italian wars of the 15th century. Future Generation Computer Systems

AFFINITIES

1. Computed over connections
2. Each edge represents the affinity between two actors

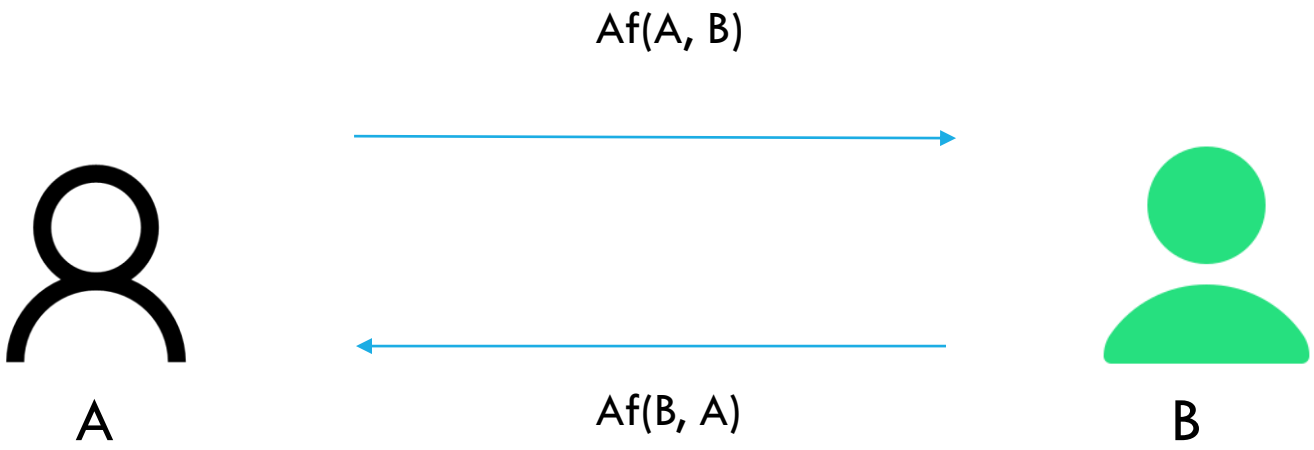


AFFINITIES

1. Defined on the [0,1] interval:
    1. 0 means no affinity
    2. 1 means total affinity
2. Zero sum game: if you spend time with one person, you spend less time with others.

GENERATING IV-AFFINITIES

Assymetric: commitment is usually different between parties.



$$Af(A, B) \neq Af(B, A)$$

COMMITMENT IN RELATIONSHIPS

$$\text{IV-Af}(A,B) = \text{IV-Af}(B, A) = (\min(\text{Af}(A, B), \text{Af}(B, A)), \max(\text{Af}(A, B), \text{Af}(B, A)))$$

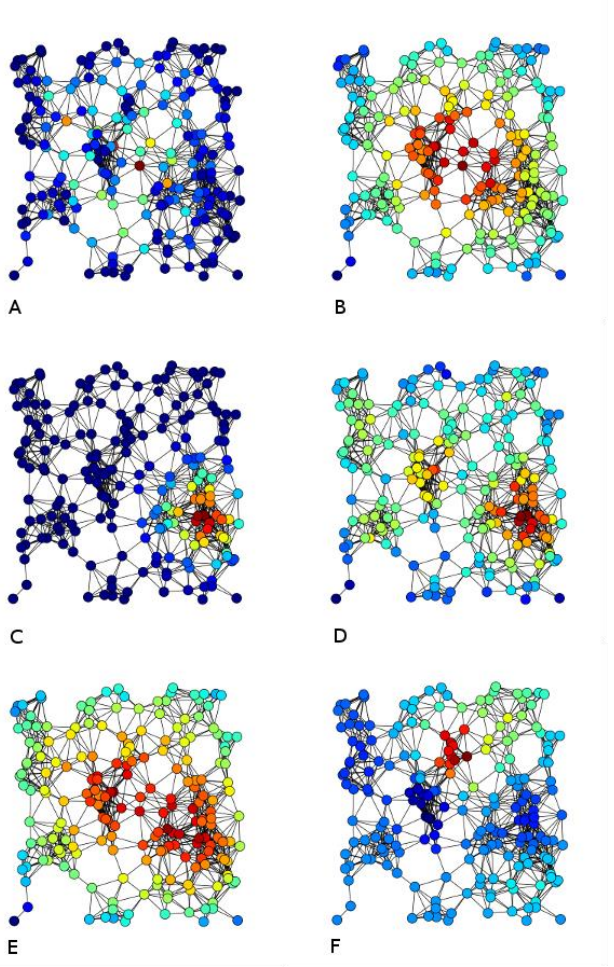
$\text{Af}(A, B) = 0.7$

$\text{Af}(B, A) = 0.3$

$\rightarrow$ $\text{IV-Af}(A, B) = \text{IV-Af}(B, A) = (0.3, 0.7)$

CENTRALITY MEASURES

- **Centrality measures** are metrics to ponder the importance of each actor in the network.
- Some prototypical examples:
  - **Degree centrality**: Node degree.
  - **Betweenness centrality**: Number of times actor X is in the shortest path between two other actors.
  - **Closenness centrality**: Average of the shortest path between X and the rest of the actors in the network.



CENTRALITY MEASURES AND COMMITMENT

1. **Assymetry**: tendency of generate different degrees of commitment. (Middle manager)
2.
3.

CENTRALITY MEASURES AND COMMITMENT

1. **Assymetry**: tendency of generate different degrees of commitment. (Middle manager)
2. **Egoism**: tendency to commit less than other people in my relationships. (Influencer)
3.

CENTRALITY MEASURES AND COMMITMENT

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3. **Altruism**: tendency to commit more than other people in my relationships. (Fan)

CENTRALITY MEASURES AND COMMITMENT

1. **Assymetry**: tendency of generate different degrees of commitment. (Middle manager)
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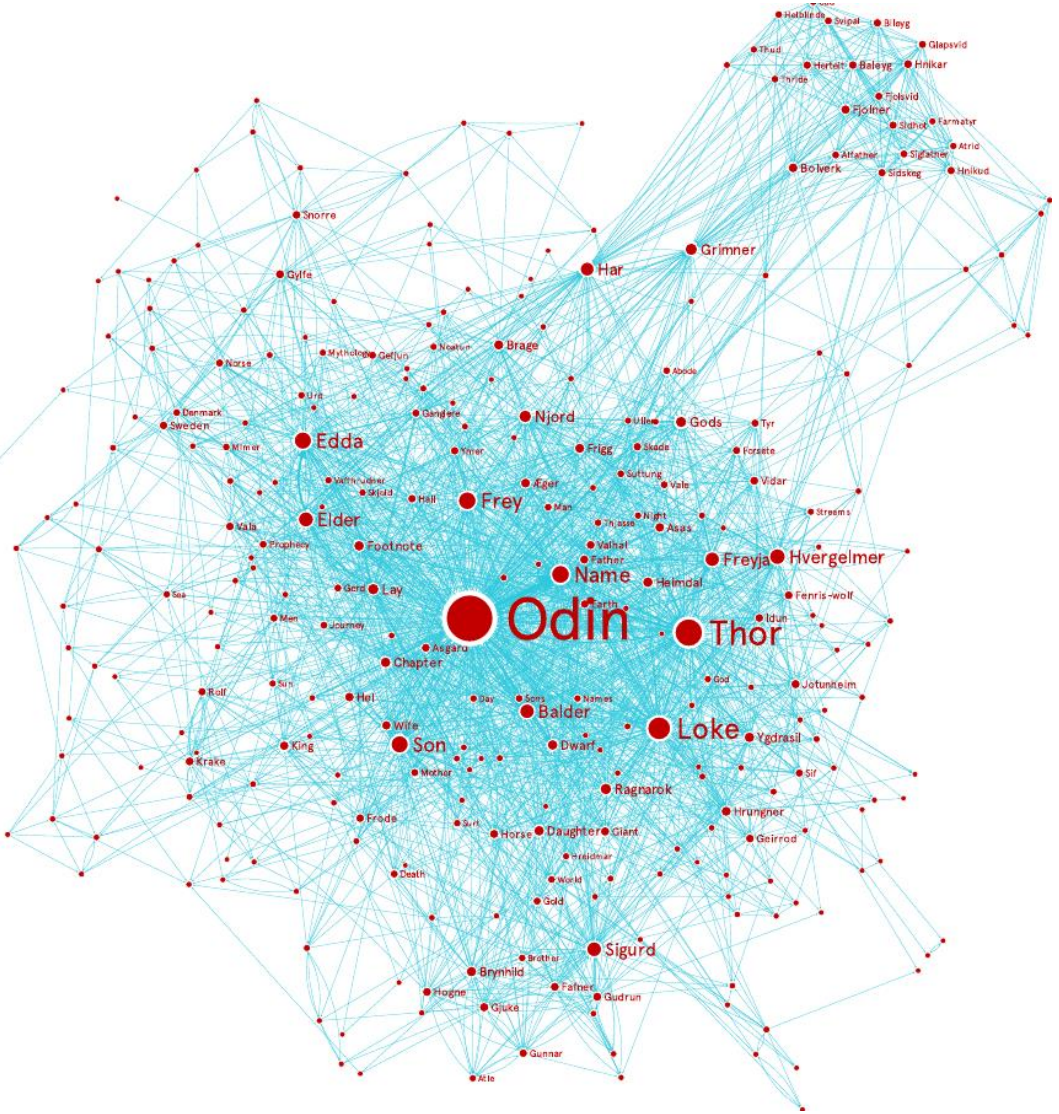
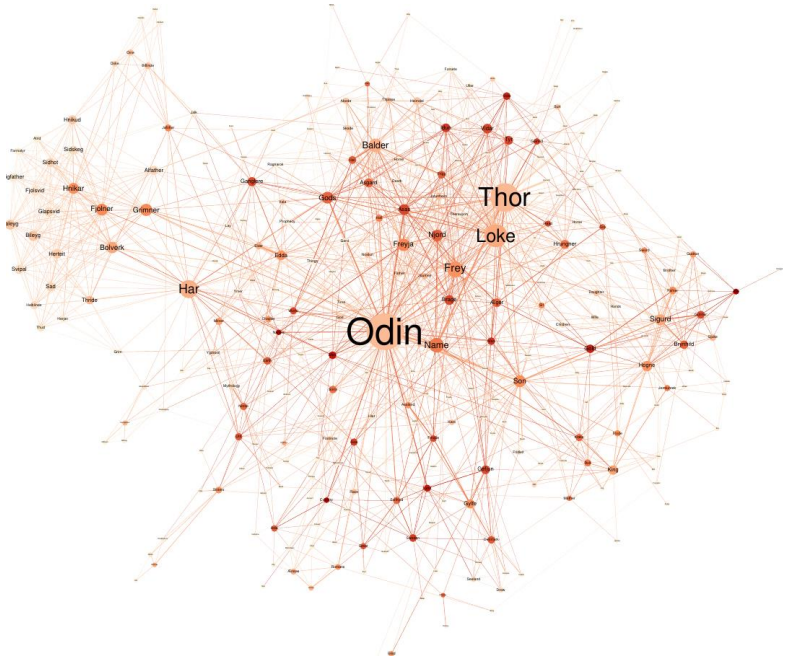
(Width of the aggregated intervals)

THE YOUNGER EDDA NETWORK

- *The Prose Edda* or the *Younger Edda* by Snorri Sturluson (1179-1241) is a medieval Icelandic compilation of mythical texts.
- The original stories contain material from traditional sources, reaching the Viking Age.
- Stories of: Odin, Thor, Loki, Ragnarök, and so on...

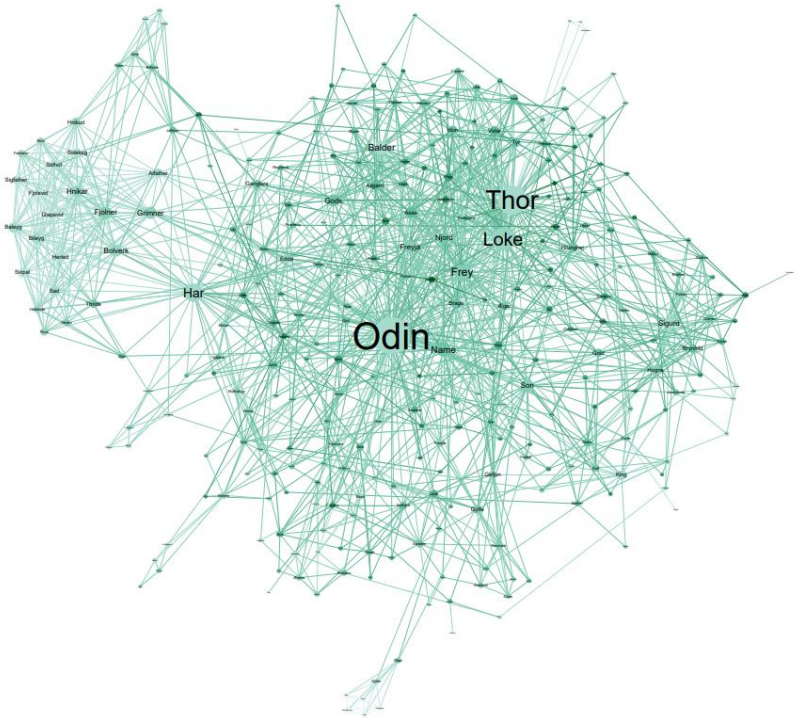


Fumanal-Idocin, J., Cordón, O., Dimuro, G., Minárová, M., & Bustince, H. (2021). The Concept of Semantic Value in Social Network Analysis: an Application to Comparative Mythology. *arXiv preprint arXiv:2109.08023*.



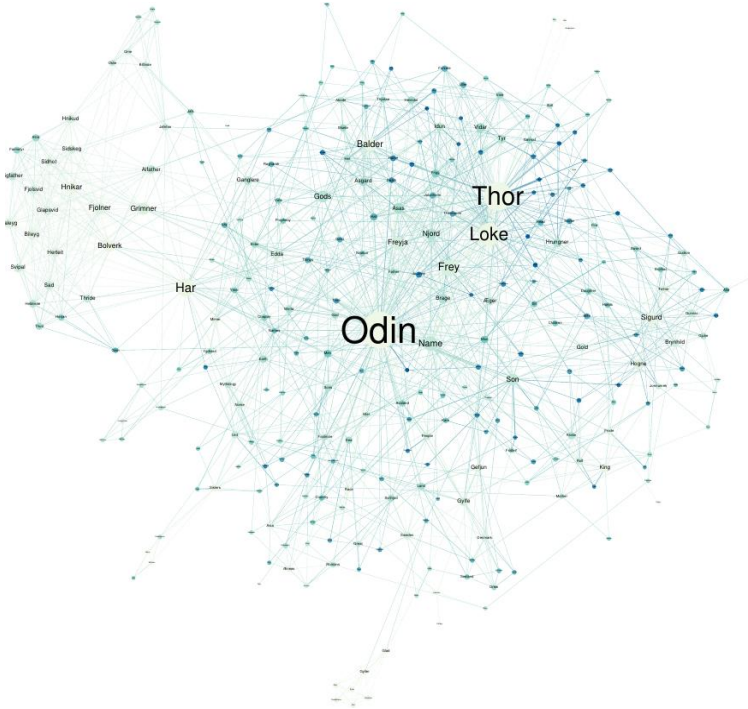
Egoism

(Influencers-like)



Assymetry

(Middle manager)



Altruism

Fan

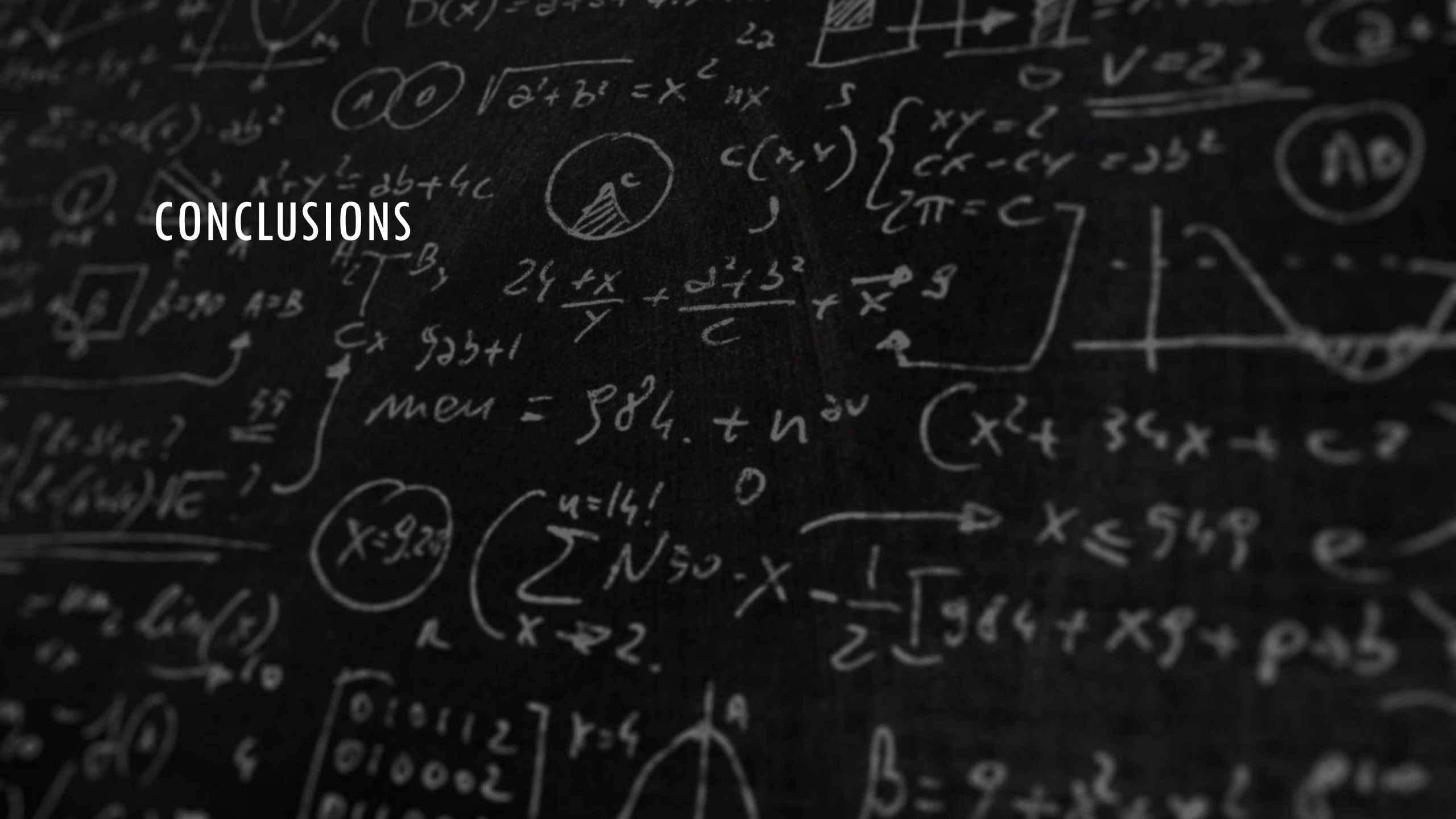
COMMITMENT CENTRALITY MEASURES RESULTS

Egoism	
Actor	Value
Atle	0.7875
Country	0.7777
Names	0.7678
Men	0.73320
Land	0.7103
Gold	0.6920
Vale	0.6748
Man	0.6443
Idun	0.6261
Geirrod	0.6124

Assymetry	
Actor	Value
Hammer	0.7808
Journey	0.7512
Drink	0.6451
Names	0.6402
Air	0.6391
Night	0.6312
River	0.62891
Jotunheim	0.6257
Head	0.6217
Giants	0.6188

Altruism	
Actor	Value
Drink	0.6451
Air	0.6391
Night	0.6312
River	0.6289
Hammer	0.6255
Giants	0.6154
Oath	0.6154
Hymer	0.5883
Sigmund	0.5865
Hermod	0.5818

CONCLUSIONS



CONCLUSIONS

1. We have studied the use of the generalized IV-Sugeno.
2. We have studied:
    1. **BCI:** As a mean to express the uncertainty in the classification choosing phase.
    2. **Social Networks:** as a mean to express difference in commitment in each relationship.
3. This aggregation process is not satisfactory with standard IV-Sugeno!

FUTURE LINES

1. Learn the measure
2. Expand to other BCI domains:
   I. Drowsiness
   II. Different Motor-Imagery tasks
   III. Cross-subject experiments
3. Reduce social network size: use the IV-Sugeno to Aggregate different actors into a single one.

Thank you!

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