AUTOMATIC DISCOVERY OF FAMILIES OF NETWORK GENERATIVE PROCESSES

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Digital Humanities
Computational Social Sciences

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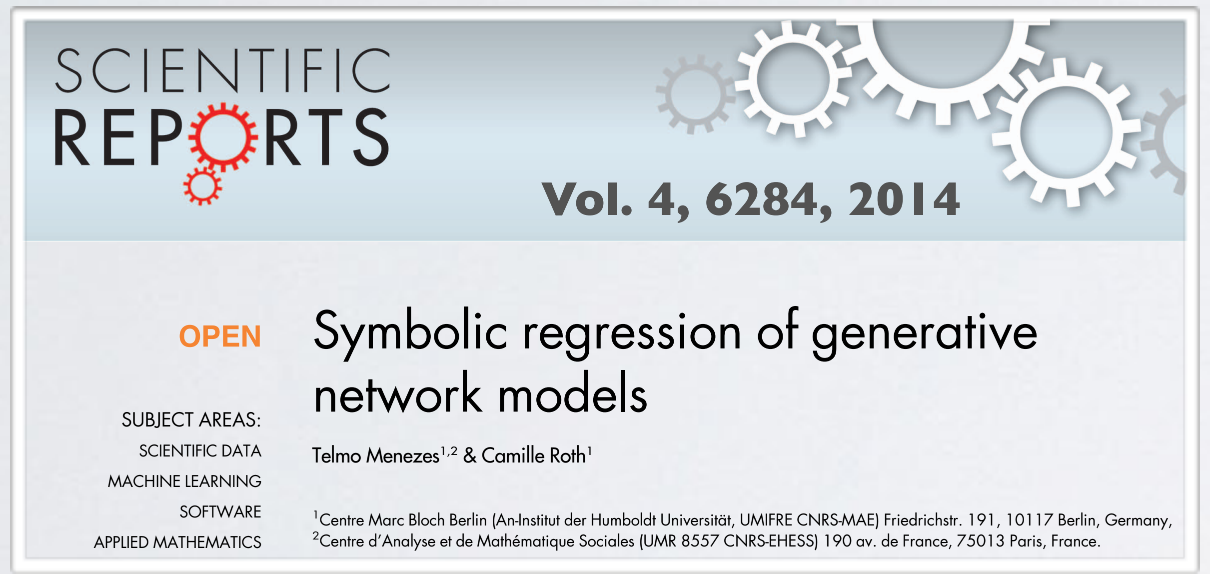
SOCIAL NETWORK FAMILIES

APPROACH

Automatic discovery of network generation laws

Menezes, Roth, 2014


SCIENTIFIC REPORTS
Vol. 4, 6284, 2014

OPEN Symbolic regression of generative network models

SUBJECT AREAS:
SCIENTIFIC DATA
MACHINE LEARNING
SOFTWARE
APPLIED MATHEMATICS

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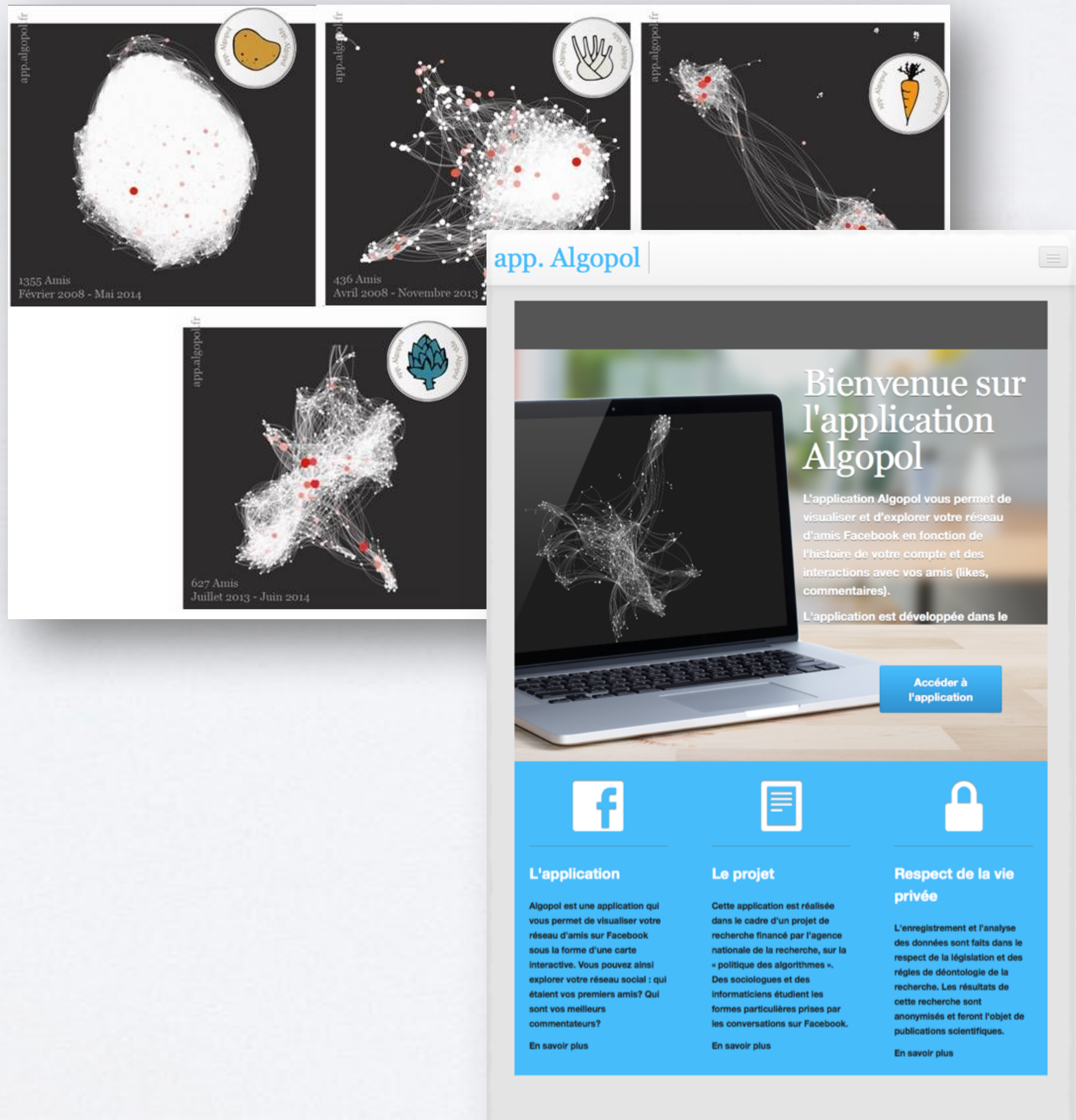
[2]Centre d'Analyse et de Mathématique Sociales (UMR 8557 CNRS-EHESS) 190 av. de France, 75013 Paris, France.

nature.com/articles/**srep06284**

FIELD

Facebook ego-centered friendship networks

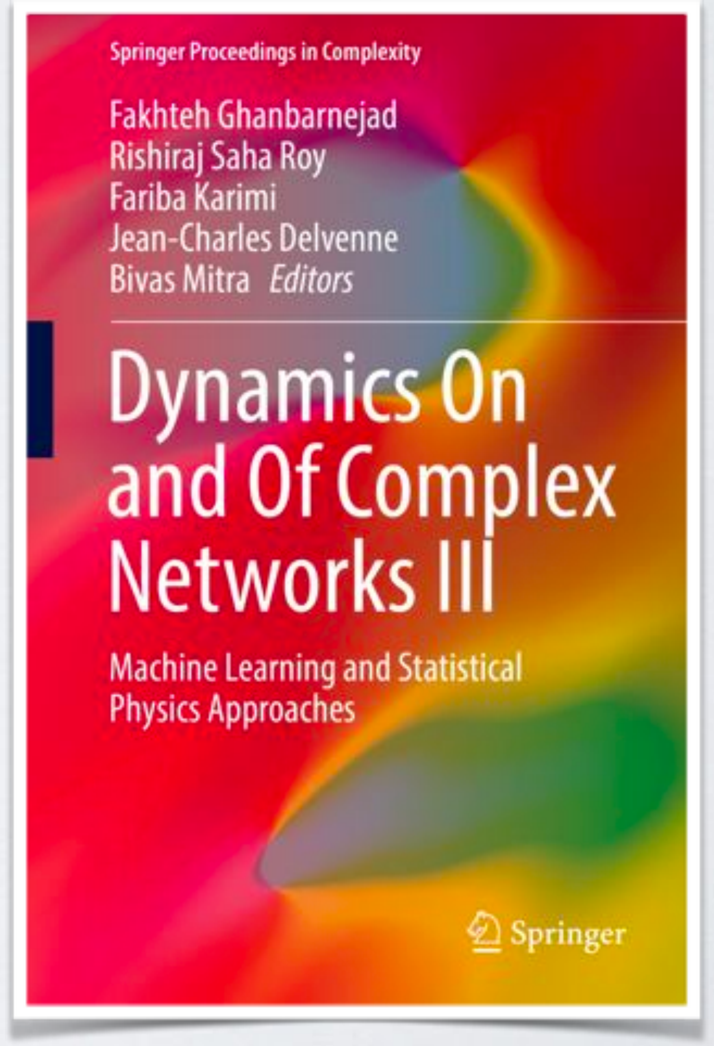
ANR Algopol, 2012-16



GOAL

Network classification according to their genotype

Menezes, Roth, 2019



arxiv.org/abs/**1906.12332**

APPROACH

NETWORK MODELS AS TREE-BASED PROGRAMS

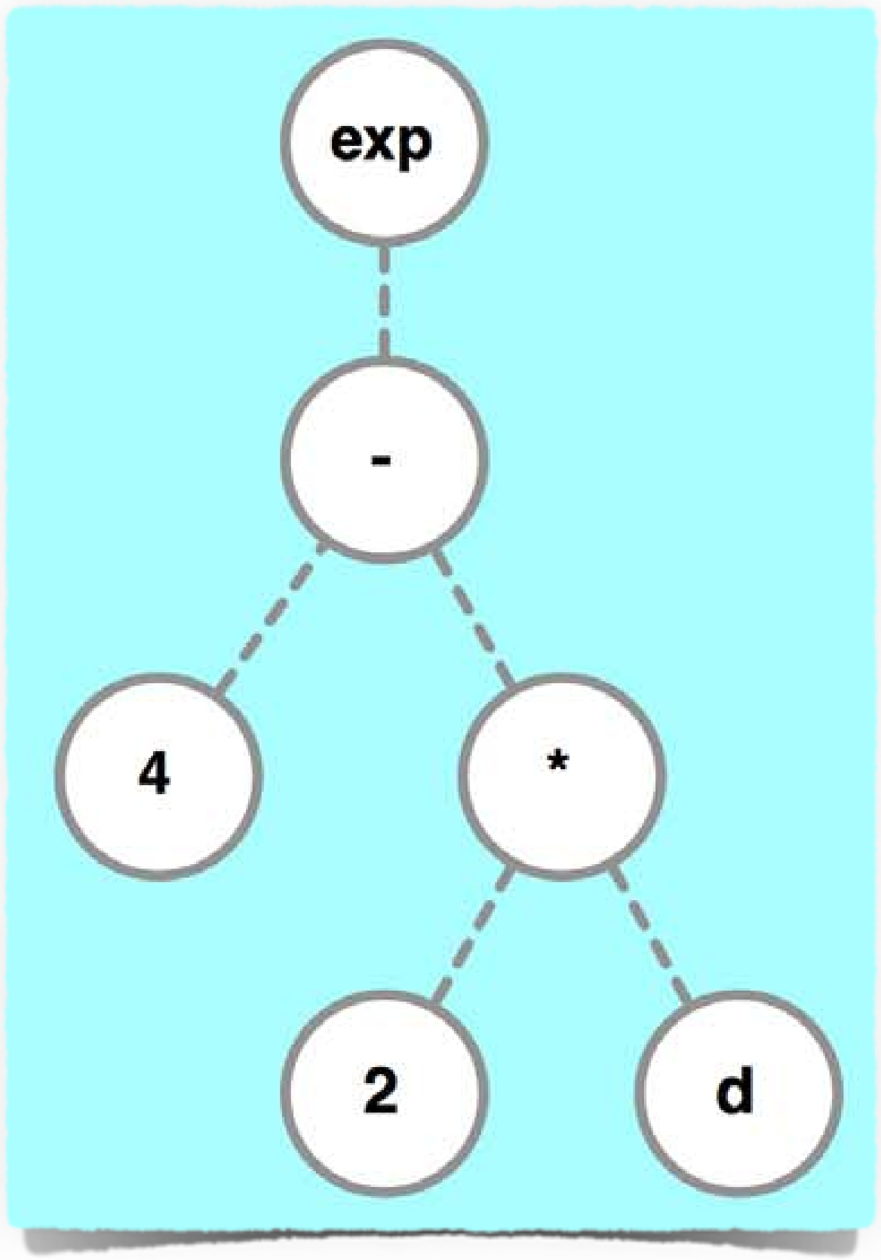
- **Vocabulary:** *k*, *d*, *i*

- **Grammar:**
  - +, -, *, /
  - x^y, e^x, log, abs, min, max
  - >, <, =, =0
  - affinity function $\psi_g(a,b)$

- **Metrics:**
  distributions on *k*, *d*, and
  triadic profiles (Milo et al. 2005)

$$P_{ij} = \frac{w_{ij}}{\sum_{(i',j')\in S} w_{i'j'}}$$

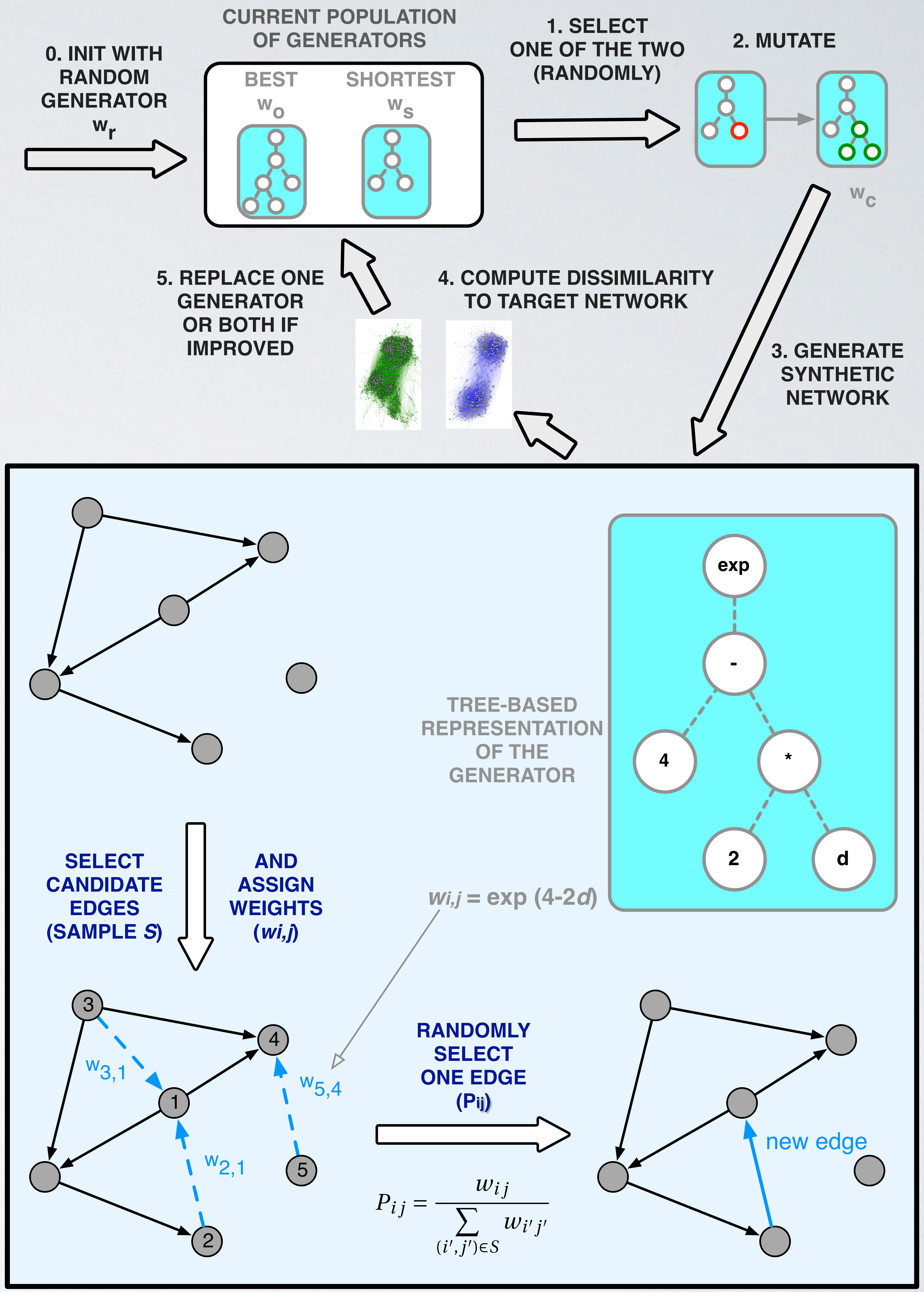
$w_{i,j} = \exp(4-2d)$



bottom-up evaluation of the tree

EVOLUTIONARY PROCESS

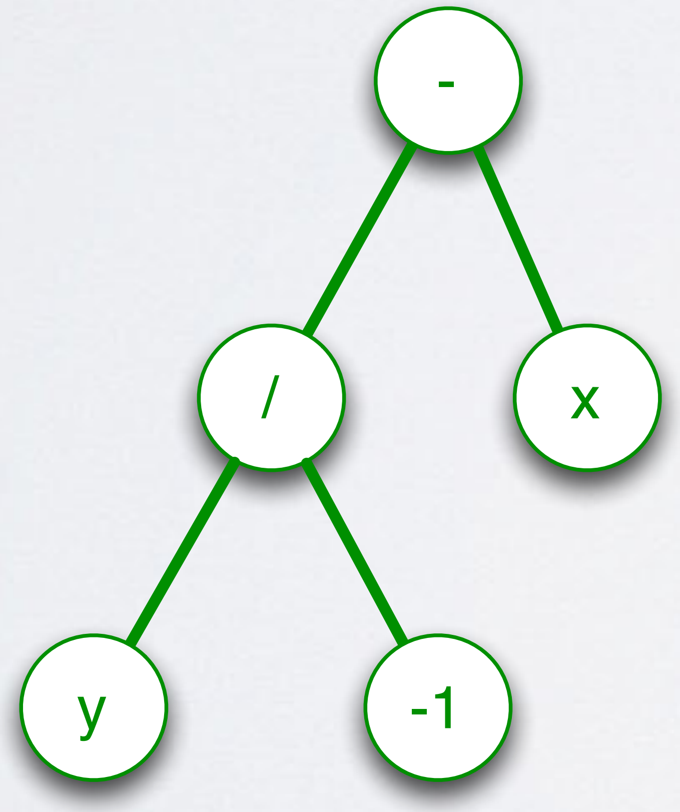
Evolutionary algorithm iteratively improves generator

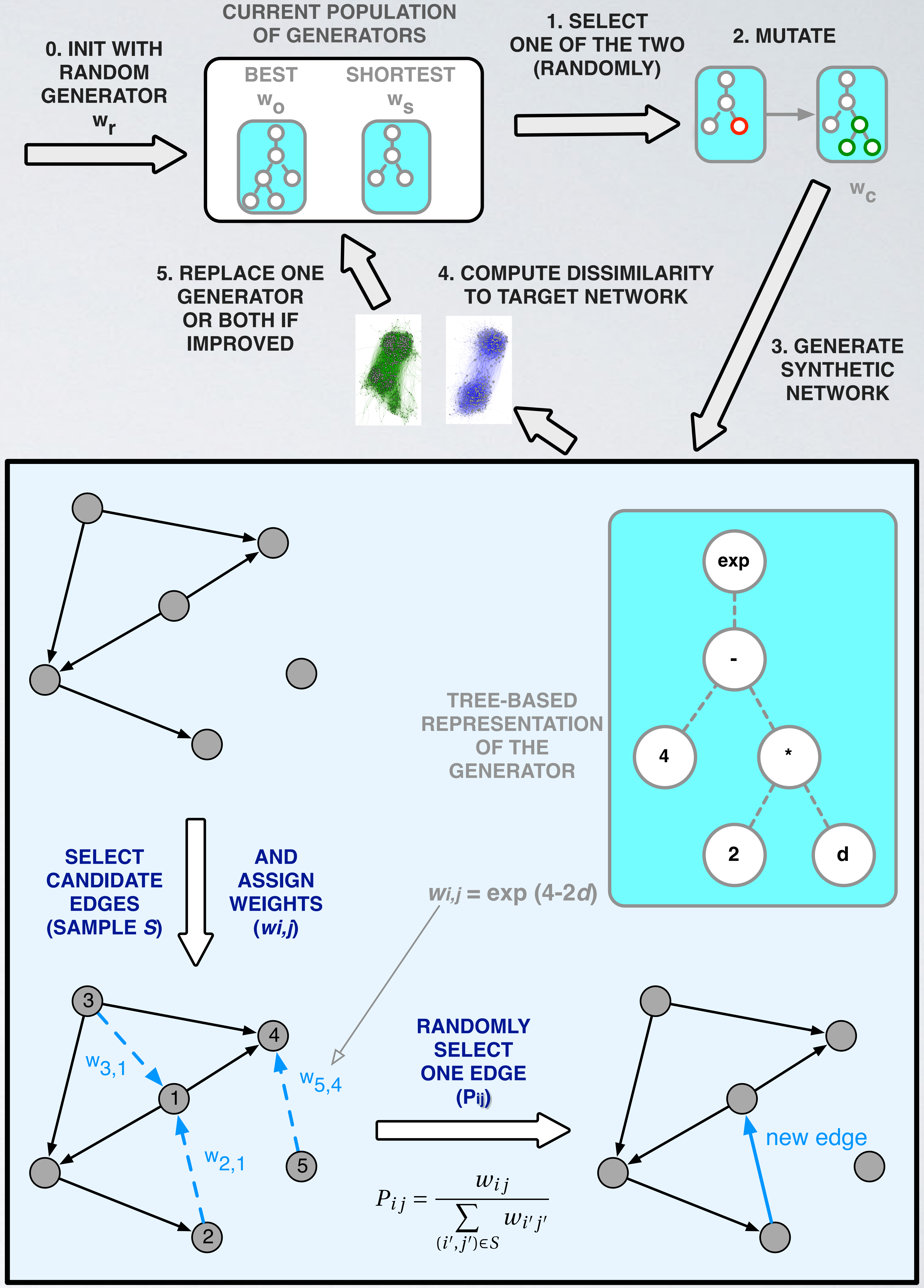


EVOLUTIONARY PROCESS

Evolutionary algorithm iteratively improves generator

Random generator:

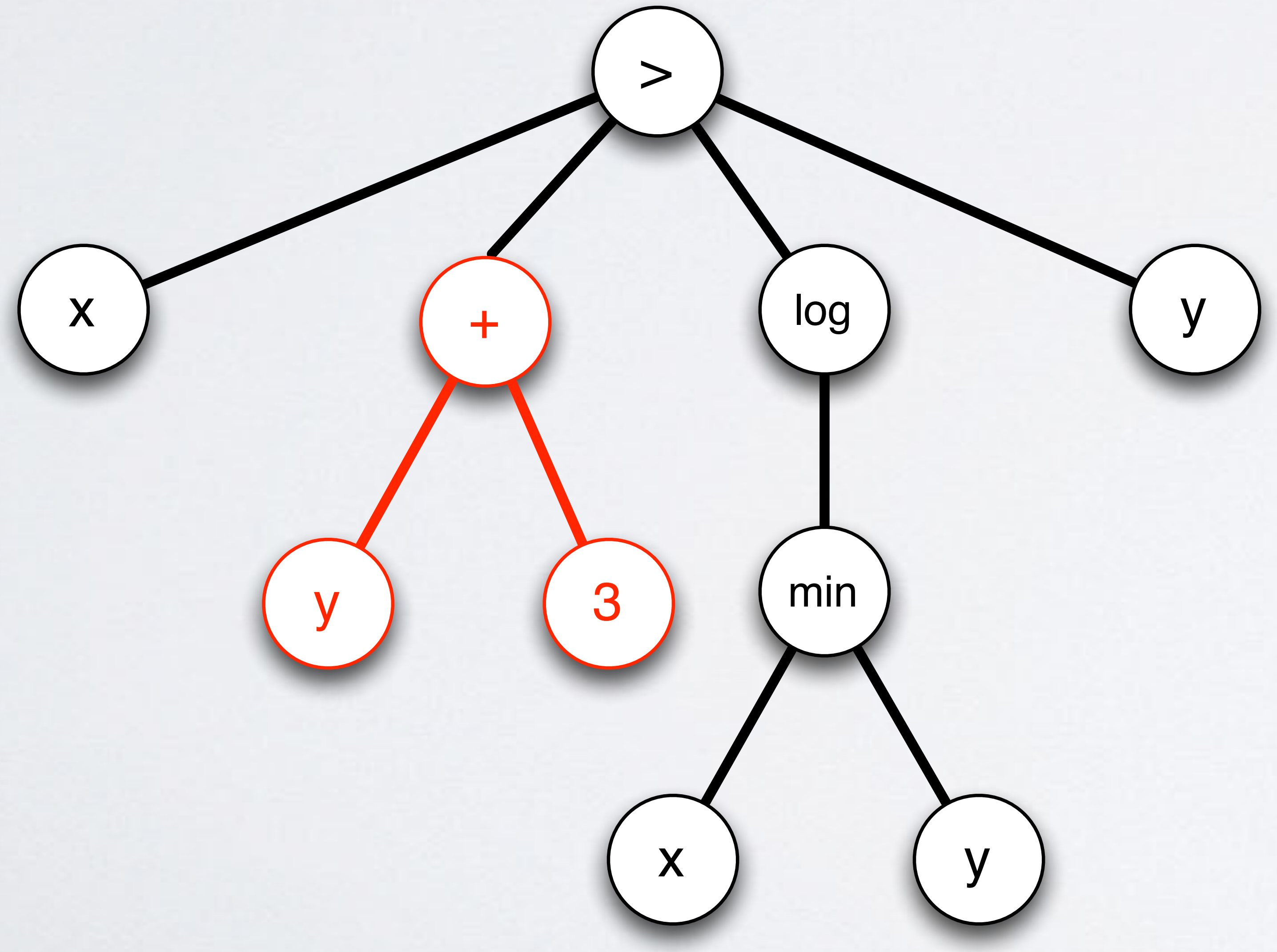


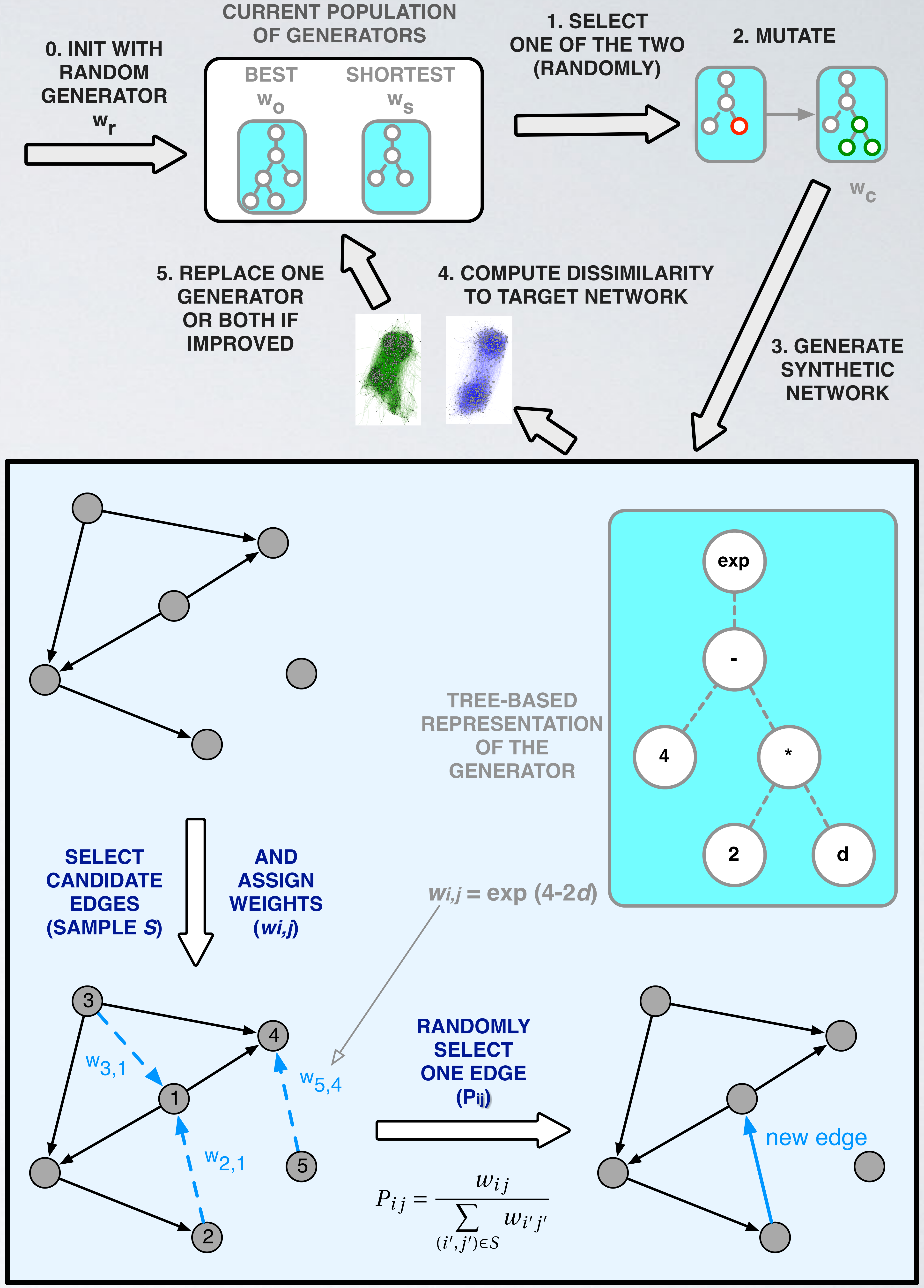


EVOLUTIONARY PROCESS

Evolutionary algorithm iteratively improves generator

Program mutation:





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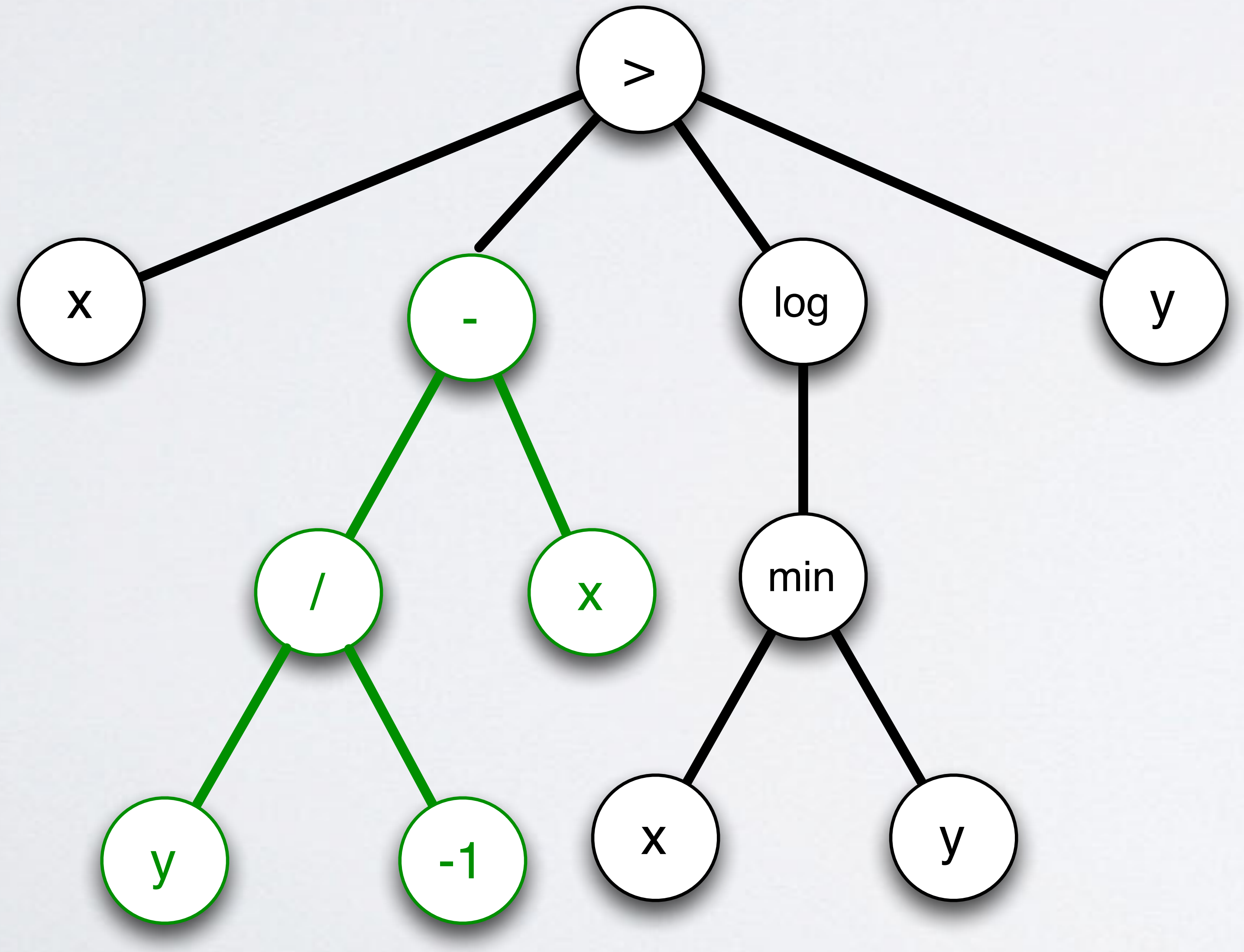
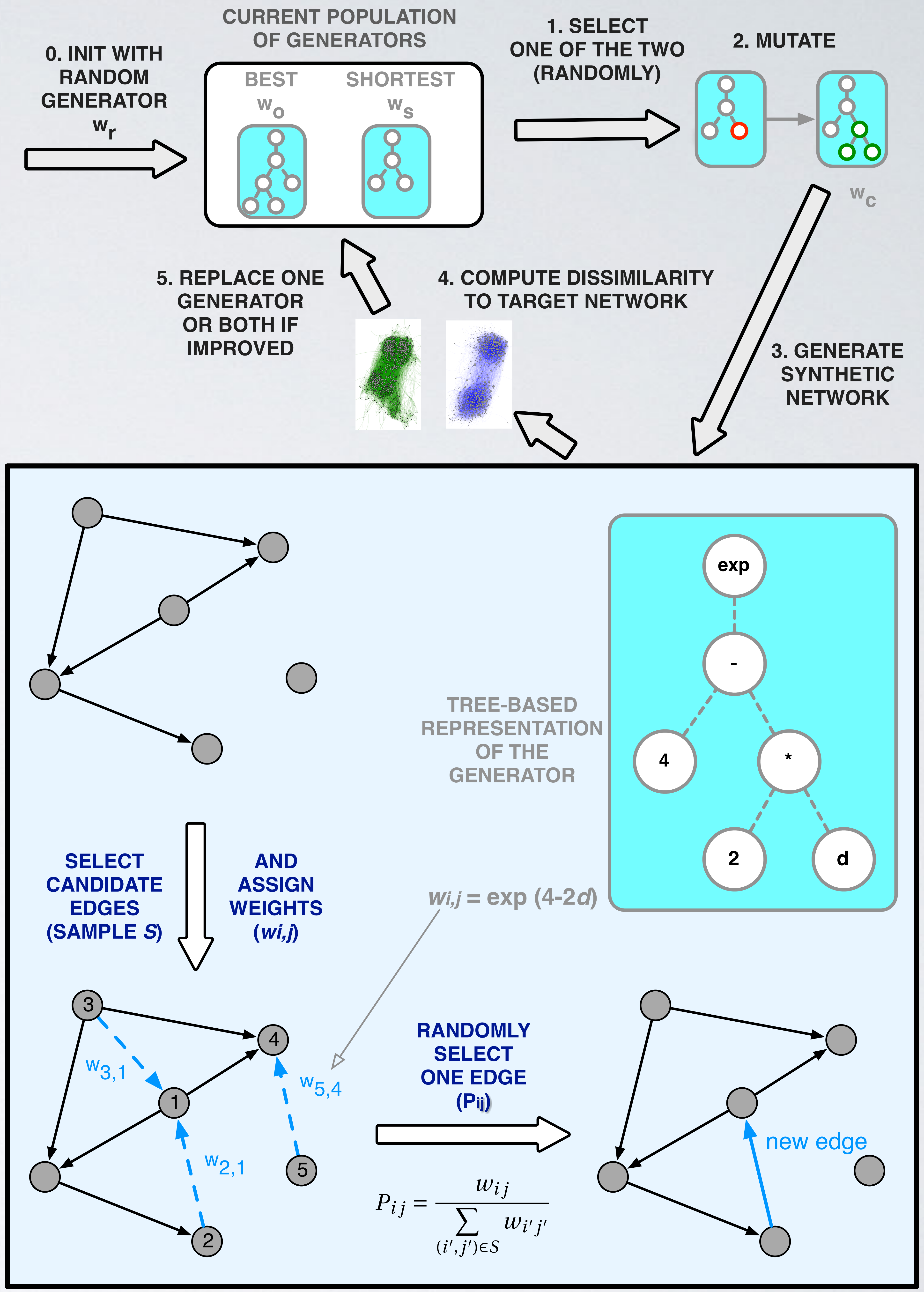




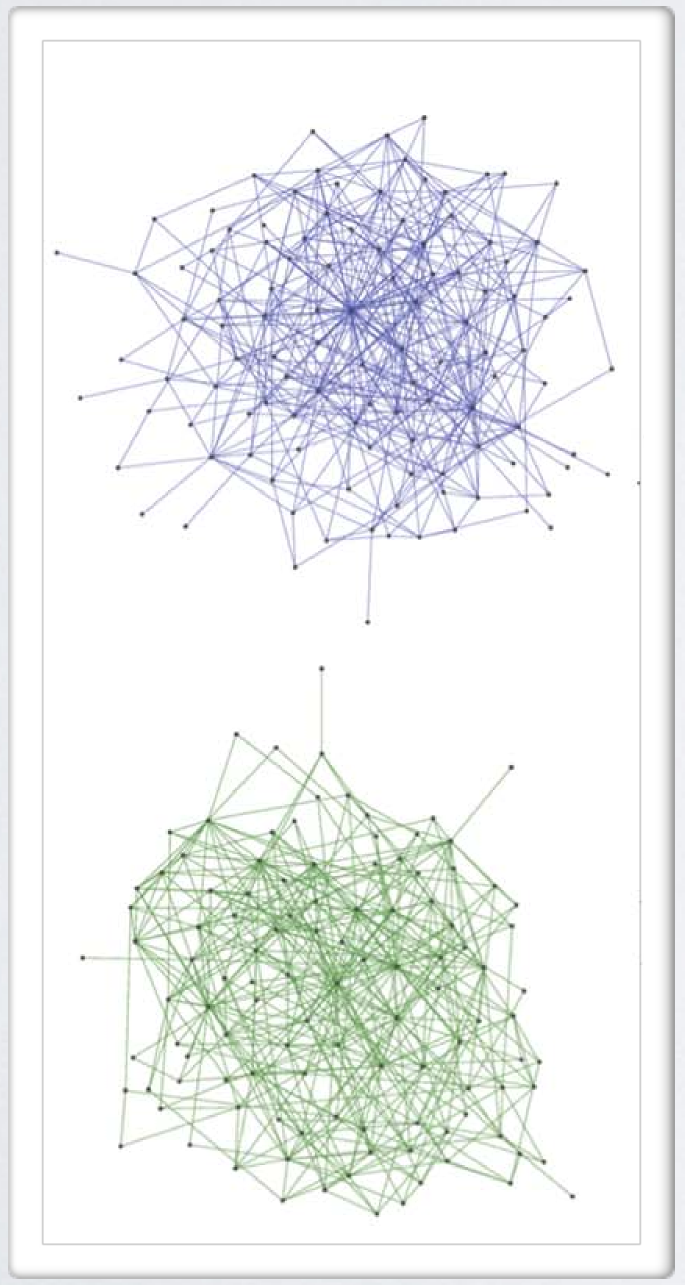
DISCOVERED GENOTYPES

Artificial basic PA : we recover $w = k$ in 100% of cases

Word adjacencies

$w = k\text{-}d$

k, yet not too far

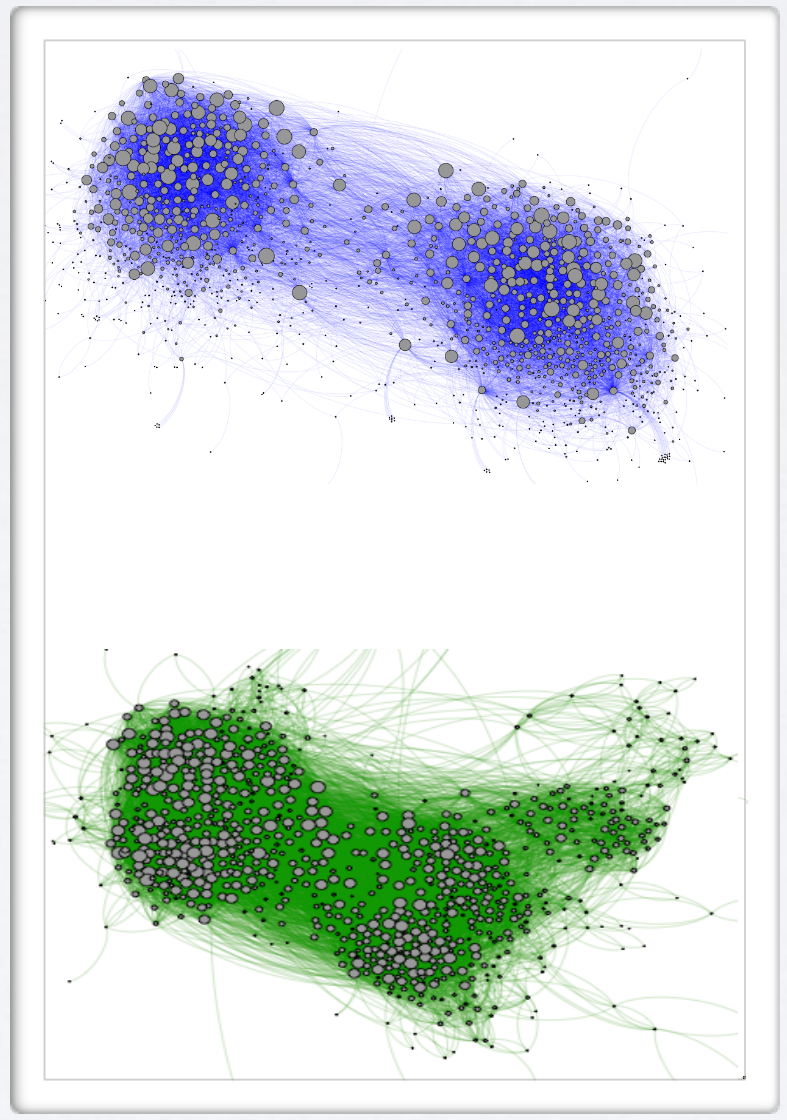


(data: Newman, 2006)

Political blogs

$w = \exp(4\text{-}2d)$

close

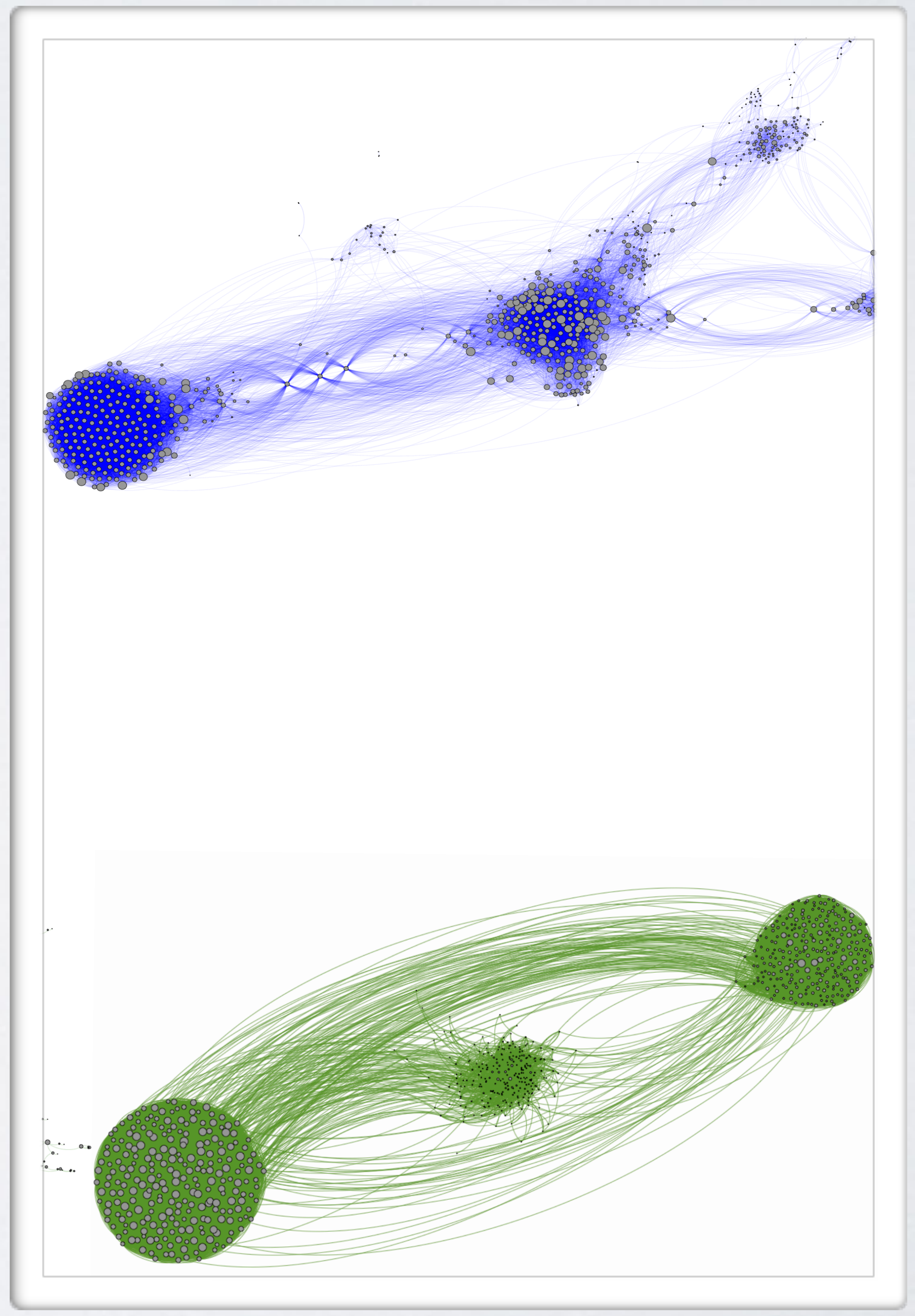


(data: Adamic & Glance, 2005)

Facebook

$w = \psi(3, i.k, k)$

3 groups, local PA



(data: Leskovec & Mc Auley, 2012)

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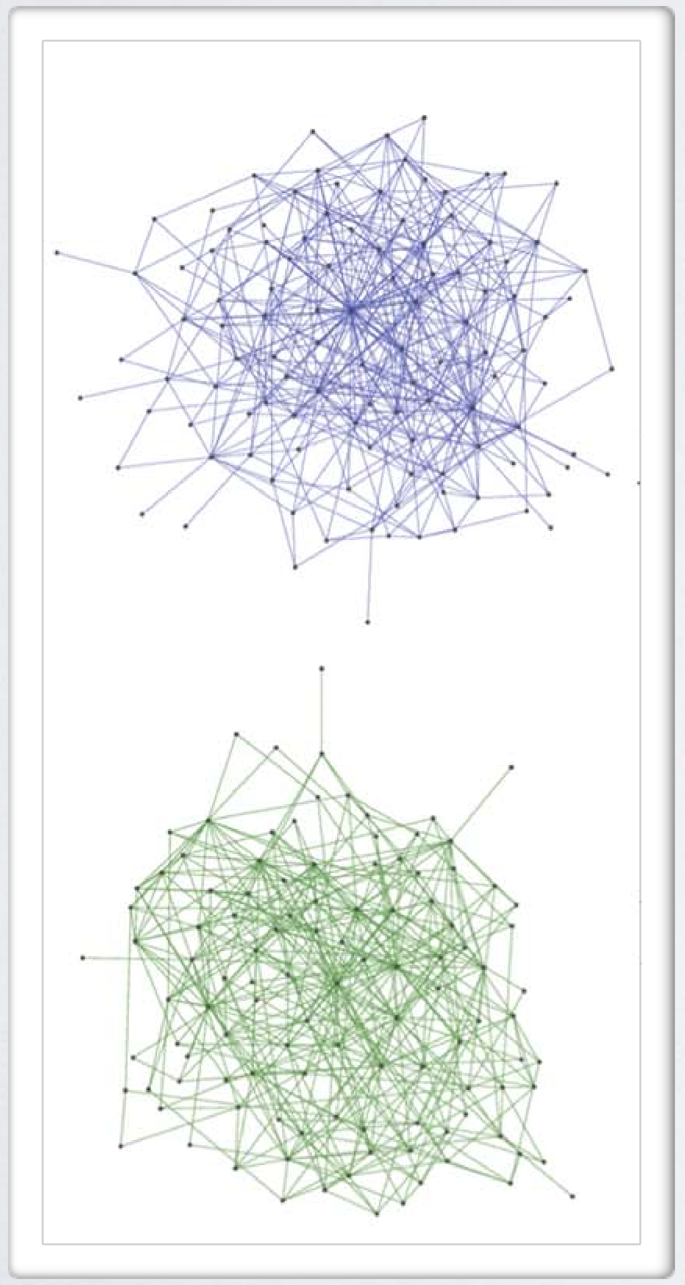

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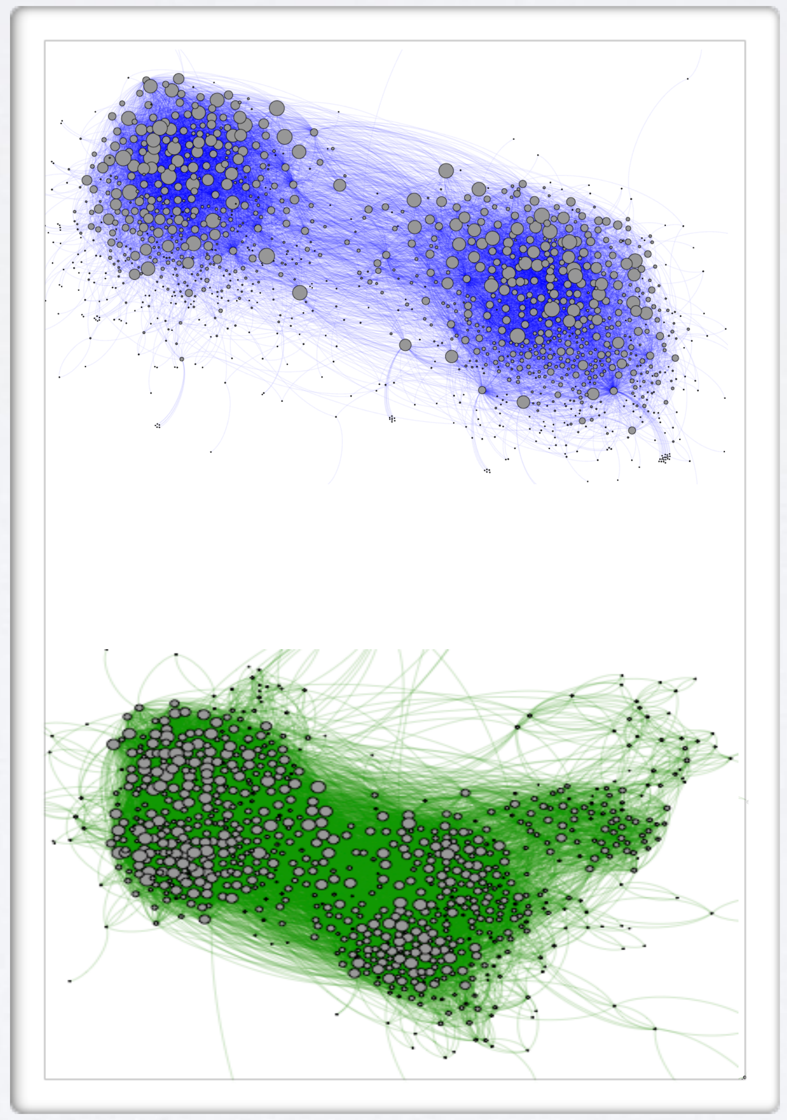

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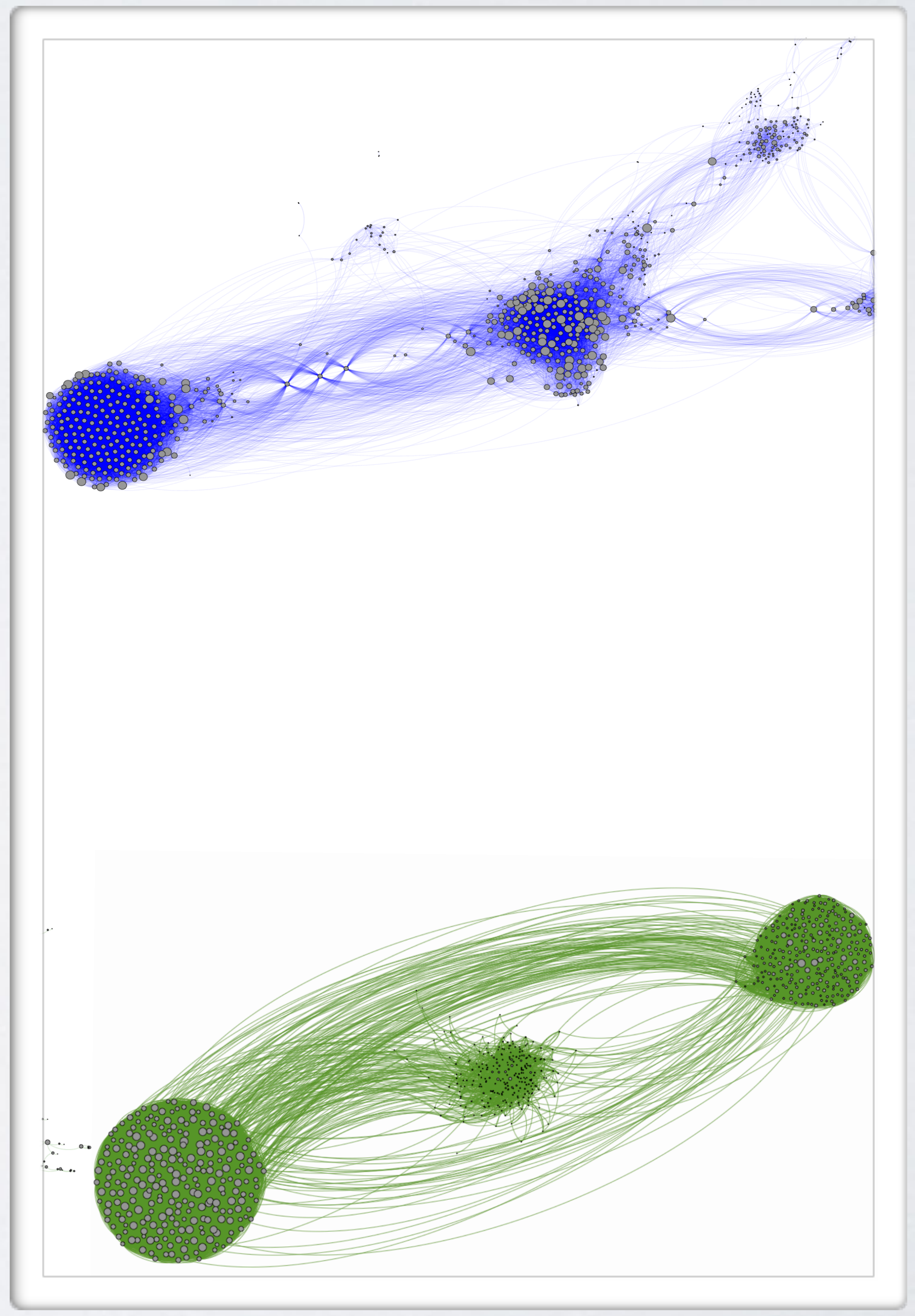
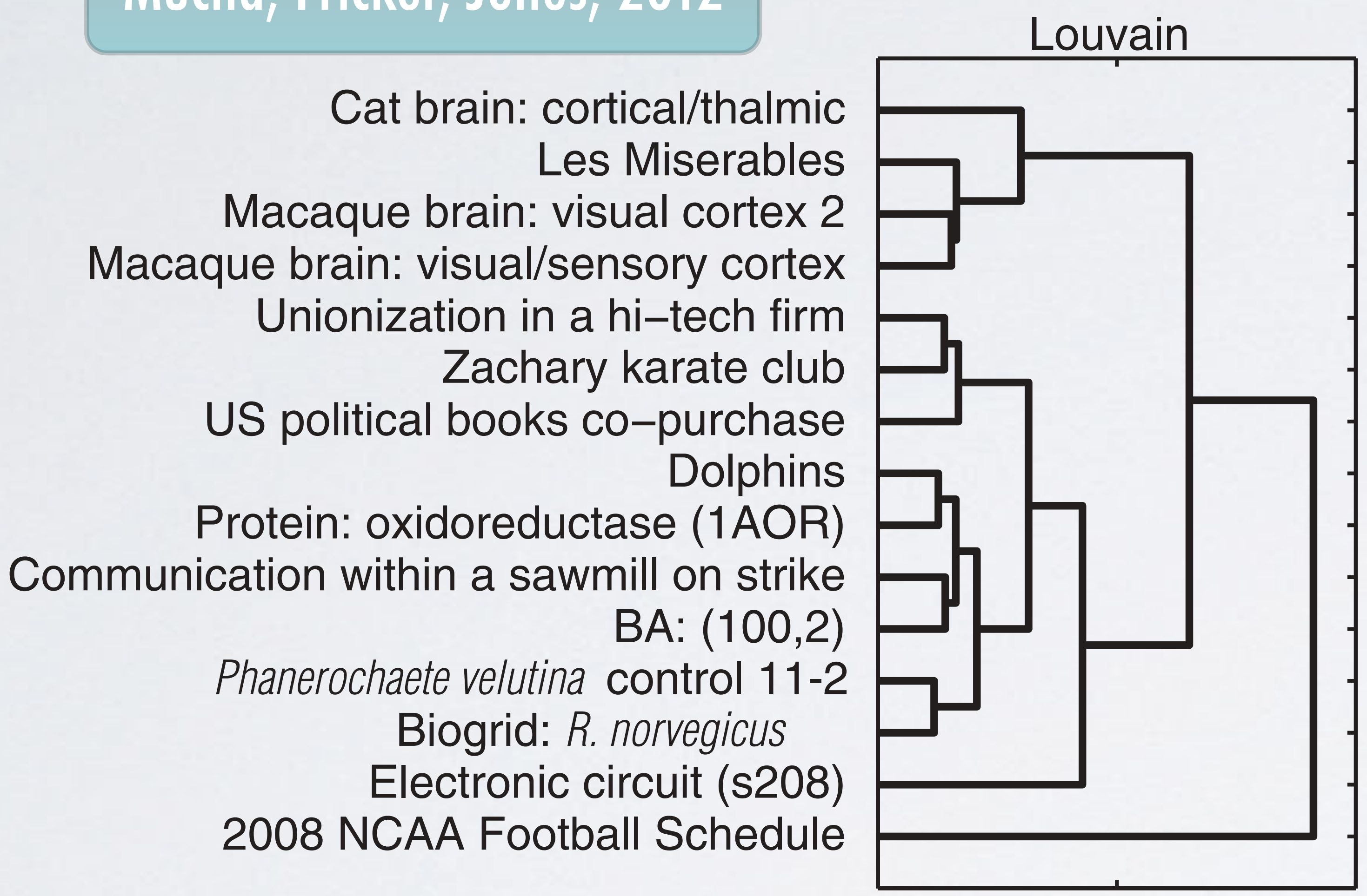


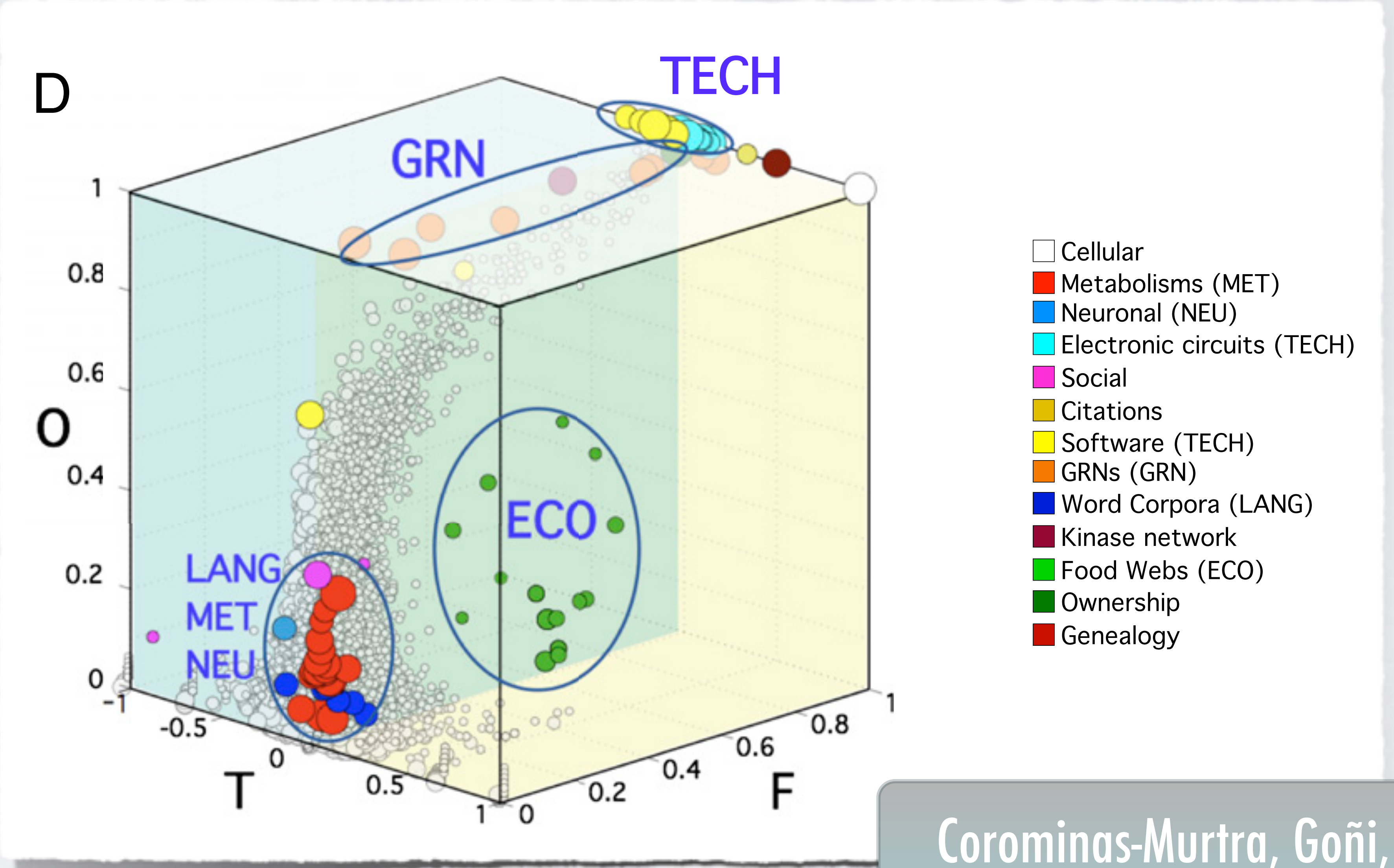
(data: Leskovec & Mc Auley, 2012)

GOAL

NETWORK CLASSIFICATION ACCORDING TO GENOTYPE

Onnela, Fenn, Reid, Porter, Mucha, Fricker, Jones, 2012



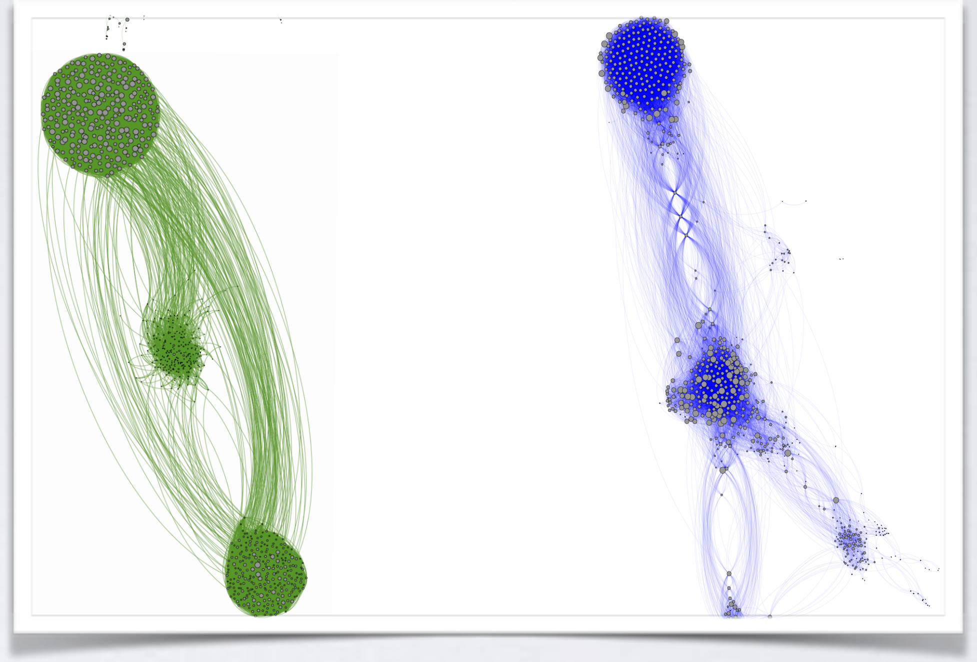


Corominas-Murtra, Goñi, Solé, Rodríguez-Caso, 2013

FIELD

FACEBOOK EGO-CENTERED FRIENDSHIP NETWORKS

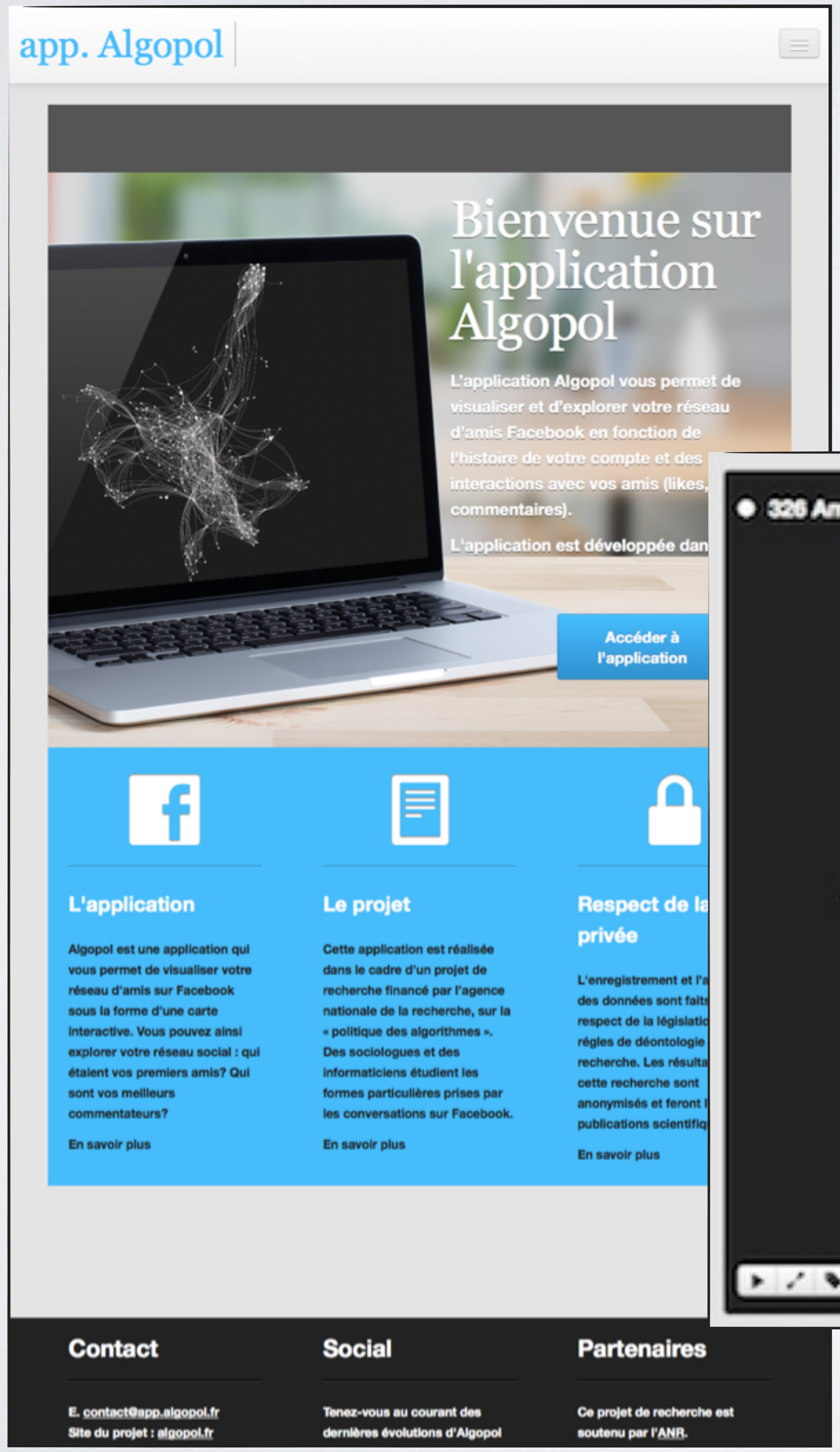
using 238 anonymized networks gathered through an online experiment 2015-16



"Algopol" application

FIELD

FACEBOOK EGO-CENTERED FRIENDSHIP NETWORKS



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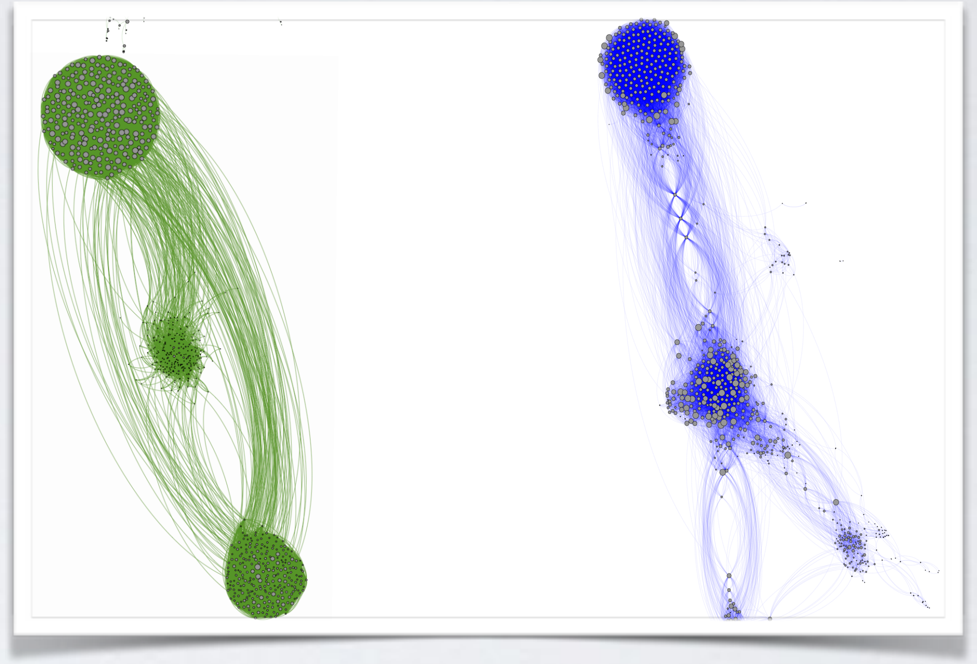

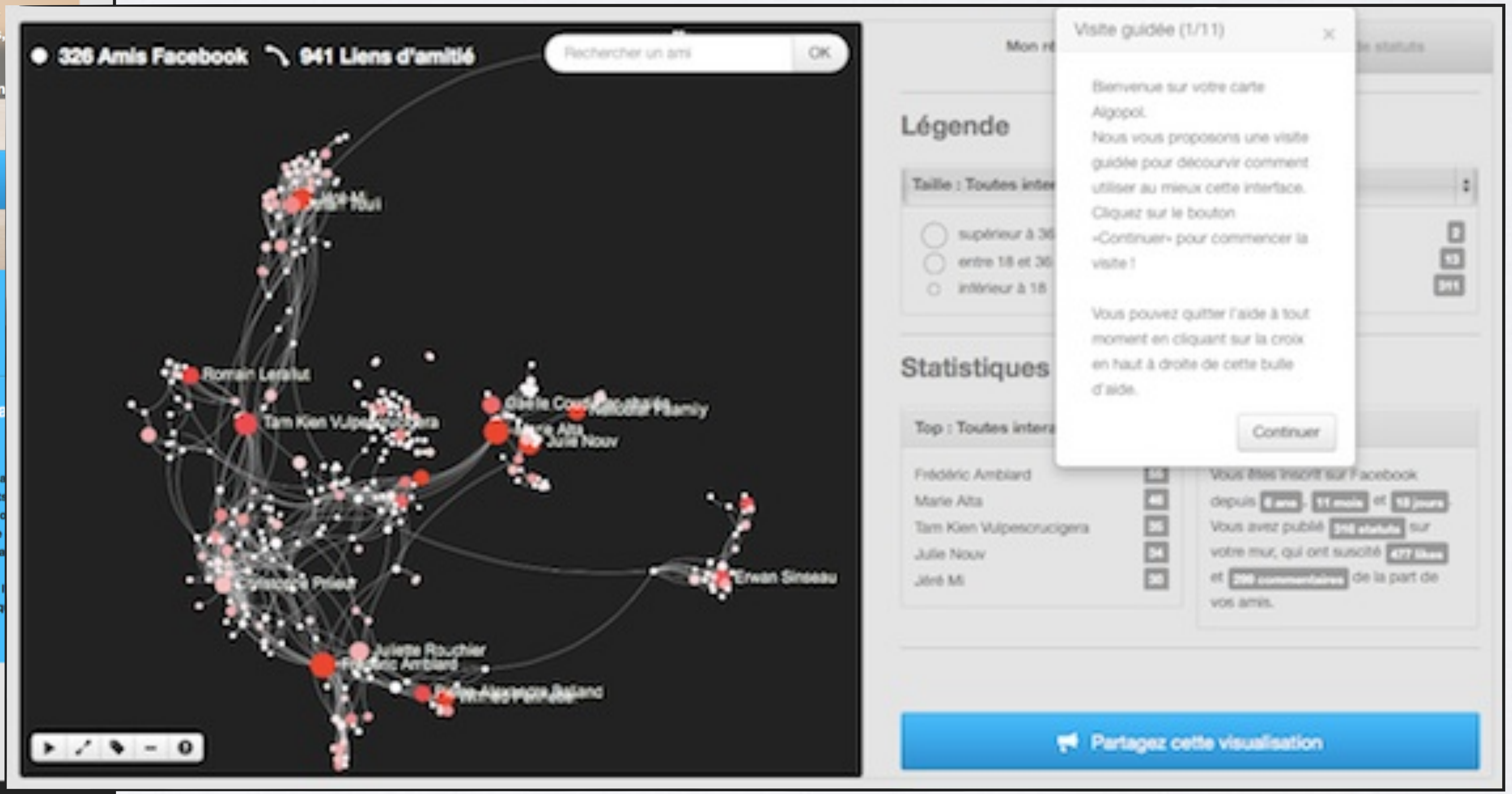

"Algopol" application

FIELD

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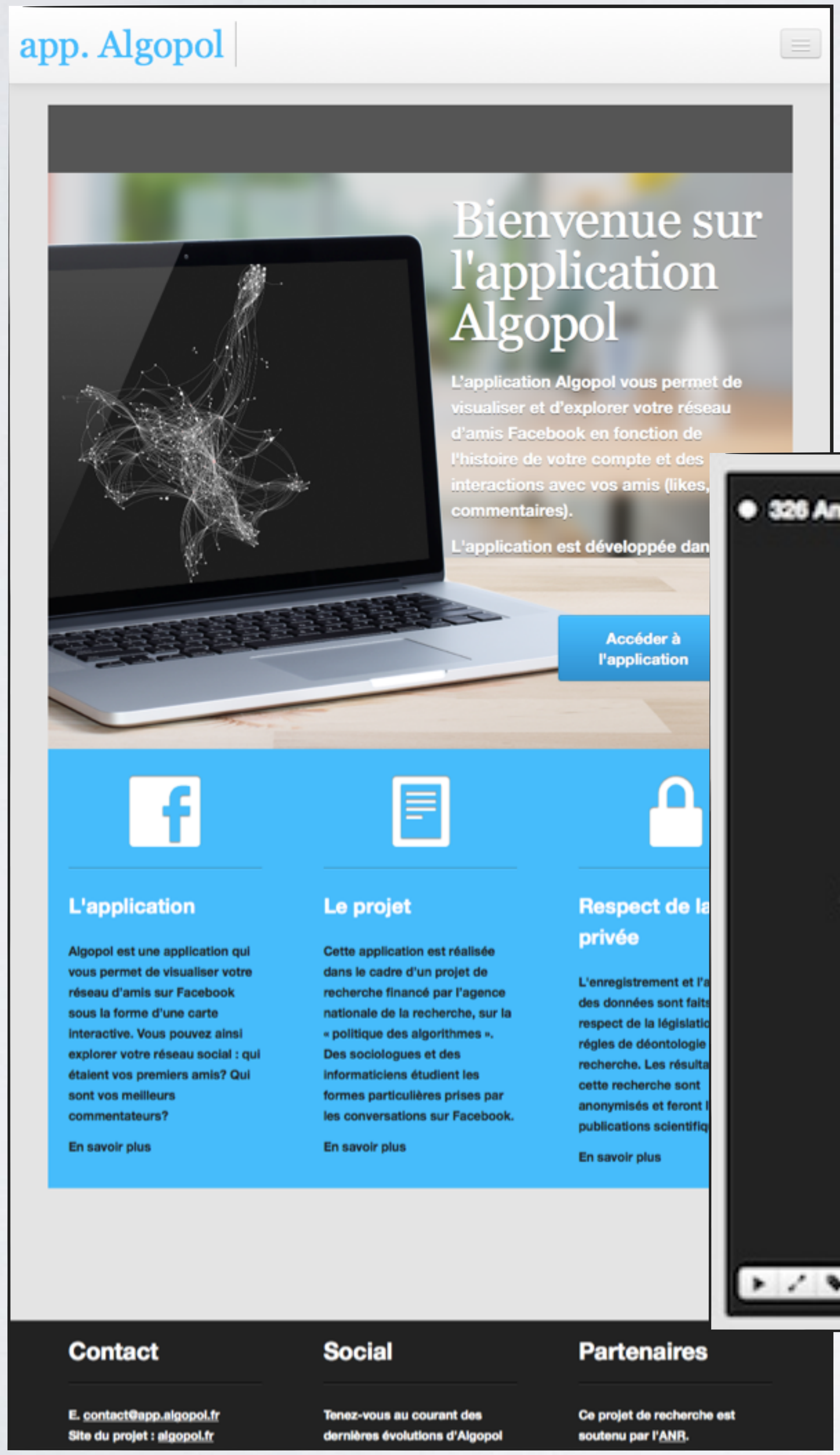

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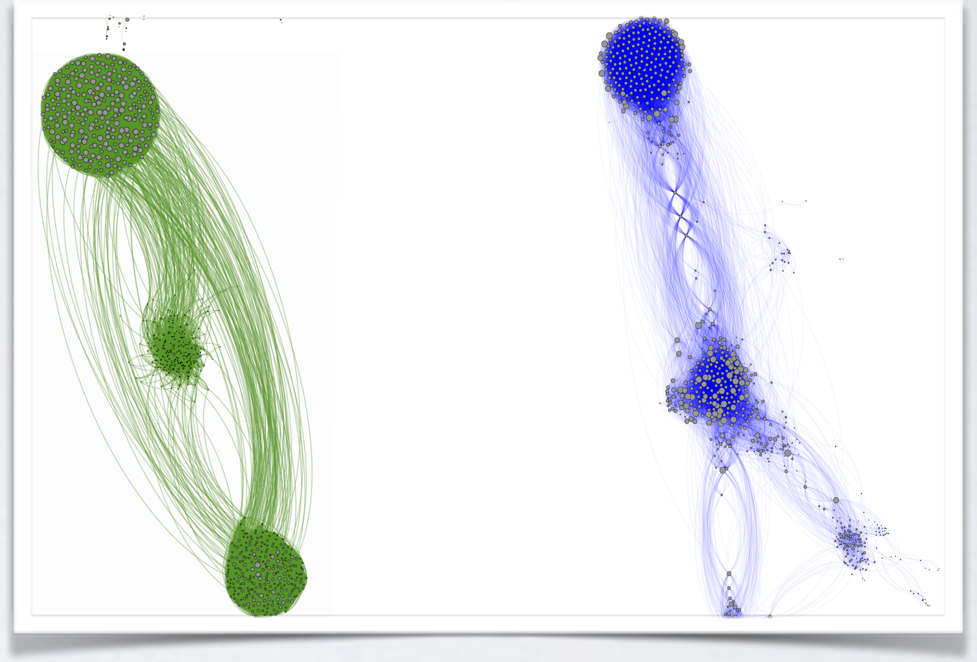

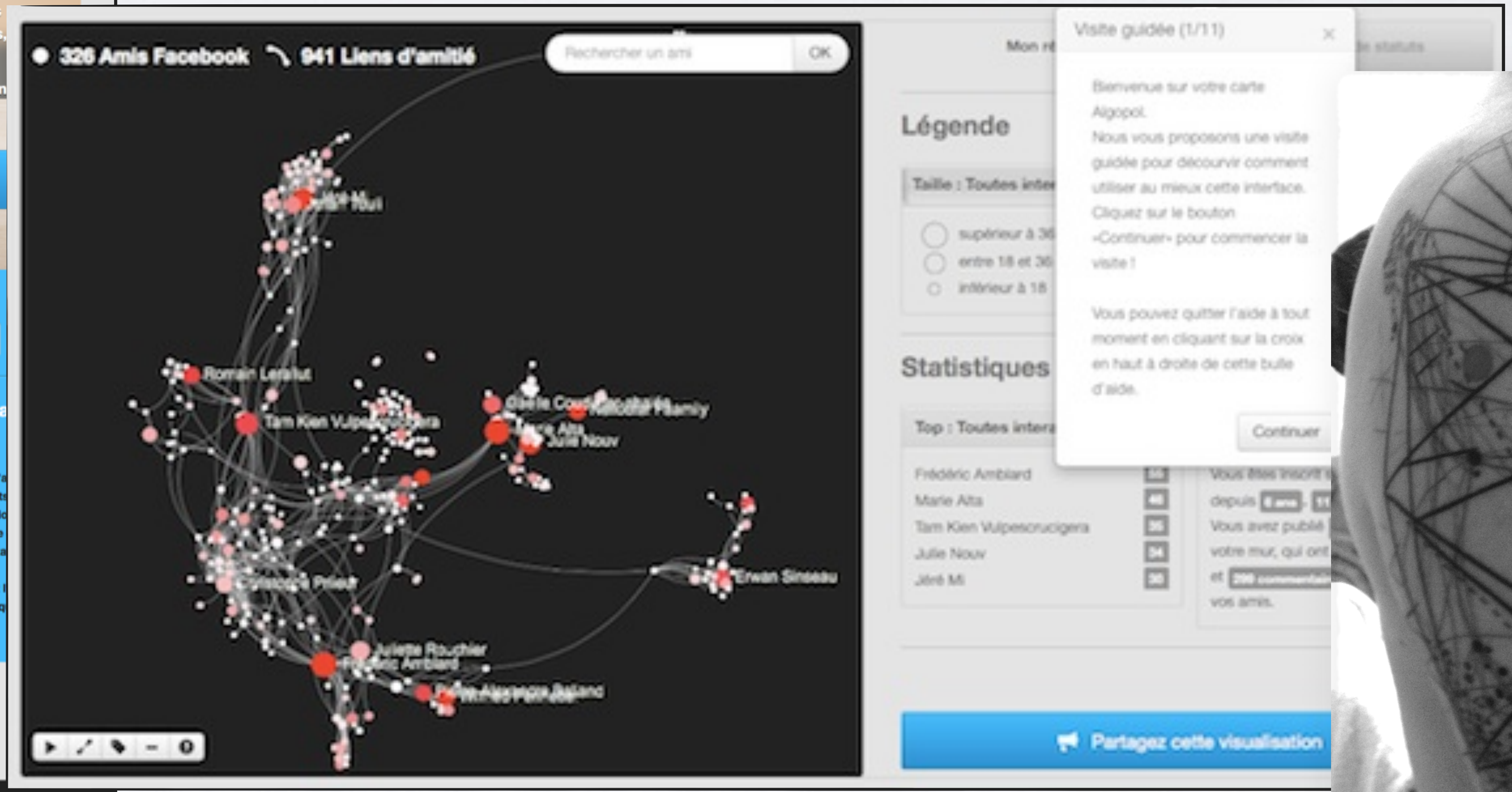

"Algopol" application

FOUND GENERATORS / GENOTYPES

Family	*List of generator functions and corresponding network number* ⟨ID⟩					
	0.08	0.88	0.95	54.6	0.62	6.0
ER	⟨14⟩	⟨50⟩	⟨78⟩	⟨82⟩	⟨108⟩	⟨124⟩
c	$(\max(k_i, i) = 0 \rightarrow 0, 0.63)$					
	⟨198⟩					
ID	i	i				
i	⟨58⟩	⟨109⟩				
ID'	e^i	e^i				
e^i	⟨18⟩	⟨139⟩				
	k	k	k	k	k	k
PA	⟨26⟩	⟨81⟩	⟨100⟩	⟨105⟩	⟨111⟩	⟨134⟩
k	k	k	k			
	⟨145⟩	⟨170⟩	⟨227⟩			
PA'	${k_j}^{k_i}$	$(\min(j, .66) > k_i \rightarrow j, e^{k_j})^{(\min((j=0, k_j, k_i), e^{k_j}))}$				${k_i}^{k_j}$
$k_i^{k_j}$	⟨0⟩	⟨47⟩				⟨193⟩
SC-α	$\psi_8(k_j^2, .62) - k_i$		$\psi_7(k^3, 4)$			
$\psi_g(k^s, c)$	⟨69⟩		⟨126⟩			
	$\psi_3(2^k, .48)$	$\psi_9(e^{k_i}, .49)$	$\psi_4(e^k, 1.1)$	$\psi_5(\frac{e^{\max(k_i, k_j)}}{k_i}, k_i)$		$\psi_5(e^k, 1)$
SC-β	⟨3⟩	⟨36⟩	⟨39⟩	⟨80⟩		⟨90⟩
$\psi_g(e^k > \frac{1}{\ldots})$	$\psi_4(e^k, 1)$	$\psi_8(e^k, d)$	$\psi_4(k_i, .67)^{k_i}$	$\psi_5(e^k, 1.7)$	$\psi_3(e^k, 2)$	

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	0.08	0.88	0.95	54.6	0.62	6.0
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ID	i	i				
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ID'	e^i	e^i				
e^i	⟨18⟩	⟨139⟩				
	k	k	k	k	k	k
PA	⟨26⟩	⟨81⟩	⟨100⟩	⟨105⟩	⟨111⟩	⟨134⟩
k	k	k	k			
	⟨145⟩	⟨170⟩	⟨227⟩			
PA'	${k_j}^{k_i}$	$(\min(j, .66) > k_i \to j, e^{k_j})^{(\min((j=0, k_j, k_i), e^{k_j}))}$				${k_i}^{k_j}$
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ID i	i ⟨58⟩	i ⟨109⟩				
ID’ e^i	e^i ⟨18⟩	e^i ⟨139⟩				
PA	k ⟨26⟩	k ⟨81⟩	k ⟨100⟩	k ⟨105⟩	k ⟨111⟩	k ⟨134⟩
k	k ⟨145⟩	k ⟨170⟩	k ⟨227⟩			
PA’ $k_i^{k_j}$	${k_j}^{k_i}$ ⟨0⟩	$(\min(j, .66) > k_i \rightarrow j, e^{k_j})^{(\min((j=0, k_j, k_i), e^{k_j}))}$ ⟨47⟩				${k_i}^{k_j}$ ⟨193⟩
SC-α	$\psi_8(k_j^2, .62) - k_i$ ⟨69⟩		$\psi_7(k^3, 4)$ ⟨126⟩			
$\psi_g(k^s, c)$						
SC-β	$\psi_3(2^k, .48)$ ⟨3⟩	$\psi_9(e^{k_i}, .49)$ ⟨36⟩	$\psi_4(e^k, 1.1)$ ⟨39⟩	$\psi_5(\frac{e^{\max(k_i, k_j)}}{k_i}, k_i)$ ⟨80⟩		$\psi_5(e^k, 1)$ ⟨90⟩
$\psi(e^k > \frac{1}{\ldots})$	$\psi_4(e^k, 1)$	$\psi_8(e^k, d)$	$\psi_4(k_i, .67)^{k_i}$	$\psi_5(e^k, 1.7)$	$\psi_2(e^k, 2)$	

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ID i	i ⟨58⟩	i ⟨109⟩				
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PA k	k ⟨26⟩	k ⟨81⟩	k ⟨100⟩	k ⟨105⟩	k ⟨111⟩	k ⟨134⟩
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PA' $k_i^{k_j}$	${k_j}^{k_i}$ ⟨0⟩	$(\min(j, .66) > k_i \to j, e^{k_j})^{(\min((j=0, k_j, k_i), e^{k_j}))}$ ⟨47⟩				$k_i^{k_j}$ ⟨193⟩
SC-α $\psi_g(k^s, c)$	$\psi_8(k_j^2, .62) - k_i$ ⟨69⟩		$\psi_7(k^3, 4)$ ⟨126⟩			
SC-β	$\psi_3(2^k, .48)$ ⟨3⟩	$\psi_9(e^{k_i}, .49)$ ⟨36⟩	$\psi_4(e^k, 1.1)$ ⟨39⟩	$\psi_5(\frac{e^{\max(k_i, k_j)}}{k_i}, k_i)$ ⟨80⟩		$\psi_5(e^k, 1)$ ⟨90⟩

SOCIAL CIRCLE (SC) GENOTYPES

SC-α $\psi_g(k^s,c)$	$\psi_8(k_j^2,.62)-k_i$ $\langle 69\rangle$		$\psi_7(k^3,4)$ $\langle 126\rangle$			
SC-β $\psi_g(e^k,>\frac{1}{2})$	$\psi_3(2^k,.48)$ $\langle 3\rangle$	$\psi_9(e^{k_i},.49)$ $\langle 36\rangle$	$\psi_4(e^k,1.1)$ $\langle 39\rangle$	$\psi_5(\frac{e^{\max(k_i,k_j)}}{k_i},k_i)$ $\langle 80\rangle$		$\psi_5(e^k,1)$ $\langle 90\rangle$
	$\psi_4(e^k,1)$ $\langle 110\rangle$	$\psi_8(e^k,d)$ $\langle 138\rangle$	$\psi_4(k_i,.67)^{k_i}$ $\langle 153\rangle$	$\psi_5(e^k,1.7)$ $\langle 213\rangle$	$\psi_3(e^k,2)$ $\langle 224\rangle$	
SC-γ $\psi_g(k^B,\sim 0)$	$\psi_9(k^k,0)$ $\langle 23\rangle$	$\psi_6(3^k,0)$ $\langle 31\rangle$	$\psi_4(4\cdot k^5,0)$ $\langle 41\rangle$	$\psi_8(k^k,0)$ $\langle 57\rangle$	$\psi_3(e^{k_i+k_j},.05)$ $\langle 97\rangle$	
	$\psi_3(e^k,0)$ $\langle 104\rangle$	$\psi_3(2^k,0)$ $\langle 127\rangle$	$\psi_6(e^{\psi_5(1,k)},0)+.07$ $\langle 141\rangle$		$\psi_7(e^k,0)$ $\langle 155\rangle$	$\psi_4(e^k,.06)$ $\langle 157\rangle$
	$\psi_2(k_i\cdot e^{k_j},0)$ $\langle 164\rangle$	$\psi_4(e^k,0)$ $\langle 177\rangle$	$\psi_5(k^7,.01)$ $\langle 235\rangle$	$\psi_5(e^k,.03)$ $\langle 236\rangle$		
SC-δ $\psi_g(e^i,*)$	$\psi_4(e^i,e^{k_i})$ $\langle 6\rangle$	$\psi_4(i^j,k_j)$ $\langle 89\rangle$	$\psi_2(j^i,k_i)$ $\langle 92\rangle$	$\psi_3(e^i,k_i)$ $\langle 121\rangle$	$\psi_3(e^i,e^7)$ $\langle 137\rangle$	$\psi_3(e^i,1)$ $\langle 148\rangle$
	$\psi_2(9^i,9^9)$ $\langle 181\rangle$	$\psi_3(e^i,j)$ $\langle 184\rangle$	$\psi_3(e^{i+j-d},e^5)$ $\langle 196\rangle$		$\psi_4(9^i,9)$ $\langle 202\rangle$	
SC-ε $\psi_g(ik,*)$	$9\psi_3(ik_i,2k_i)$ $\langle 9\rangle$	$\psi_4(ik_j,6k_j)$ $\langle 24\rangle$	$\psi_5(jk_j,k_j)$ $\langle 25\rangle$	$\psi_9(ik_i,.1k_i)$ $\langle 37\rangle$	$\psi_2(jk_j,k_j)$ $\langle 75\rangle$	$\psi_7(jk_j,7k_j)$ $\langle 91\rangle$
	$\psi_6(ik_i,.44k_i)$ $\langle 106\rangle$	$\psi_4(jk_i,.38)$ $\langle 107\rangle$	$\psi_3(jk_i,k_j)$ $\langle 115\rangle$	$\psi_4(i\log(k_i),0)$ $\langle 165\rangle$		$\psi_3(jk_i,\frac{k_i}{4})$ $\langle 166\rangle$
	$(\frac{k_jk_i}{.66}+d)\psi_4(j,.61)$ $\langle 188\rangle$		$\psi_3(ik_j,2k_j)$ $\langle 194\rangle$	$\psi_3(ik_j,k_j)$ $\langle 206\rangle$	$\psi_3(ik_i,0)$ $\langle 209\rangle$	$\psi_4(ik_i,3k_i)$ $\langle 218\rangle$
SC-ζ $\psi_g(i^k,*)$	$\psi_7(i,0)^{k_j}$ $\langle 68\rangle$	$\frac{7}{d}\psi_4(i^{k_i},.48)$ $\langle 93\rangle$	$\psi_4(\frac{i^{k_j}}{k_j},.18)$ $\langle 95\rangle$	$\psi_8(i^{k_i},2)$ $\langle 125\rangle$	$\psi_4(i^{k_i},0)$ $\langle 156\rangle$	$\psi_4(\frac{1}{6}i^{k_i},d)$ $\langle 179\rangle$
	$\psi_9(dj^{k_i},0)$ $\langle 185\rangle$	$\psi_{\min(i,4)}(i^{k_i},0)$ $\langle 195\rangle$		$\psi_5(9j^{k_i},.03)$ $\langle 219\rangle$		
SC-η $\psi_g(ik^2,*)$	$\psi_5((ik_i)^2,i)$ $\langle 16\rangle$	$\psi_5(ik_i{}^2,6)$ $\langle 128\rangle$	$\psi_4(2980.96k^2,2k)$ $\langle 132\rangle$		$\psi_2(ik_j{}^2,k_j{}^2)$ $\langle 163\rangle$	
	$\psi_7(\psi_i(.5,k_j{}^2),0)$ $\langle 182\rangle$					
SC-θ $\psi_g(k,0)-1$	$\psi_4(k,0)-.99$ $\langle 8\rangle$		$\psi_7(k,0)-.93$ $\langle 83\rangle$			

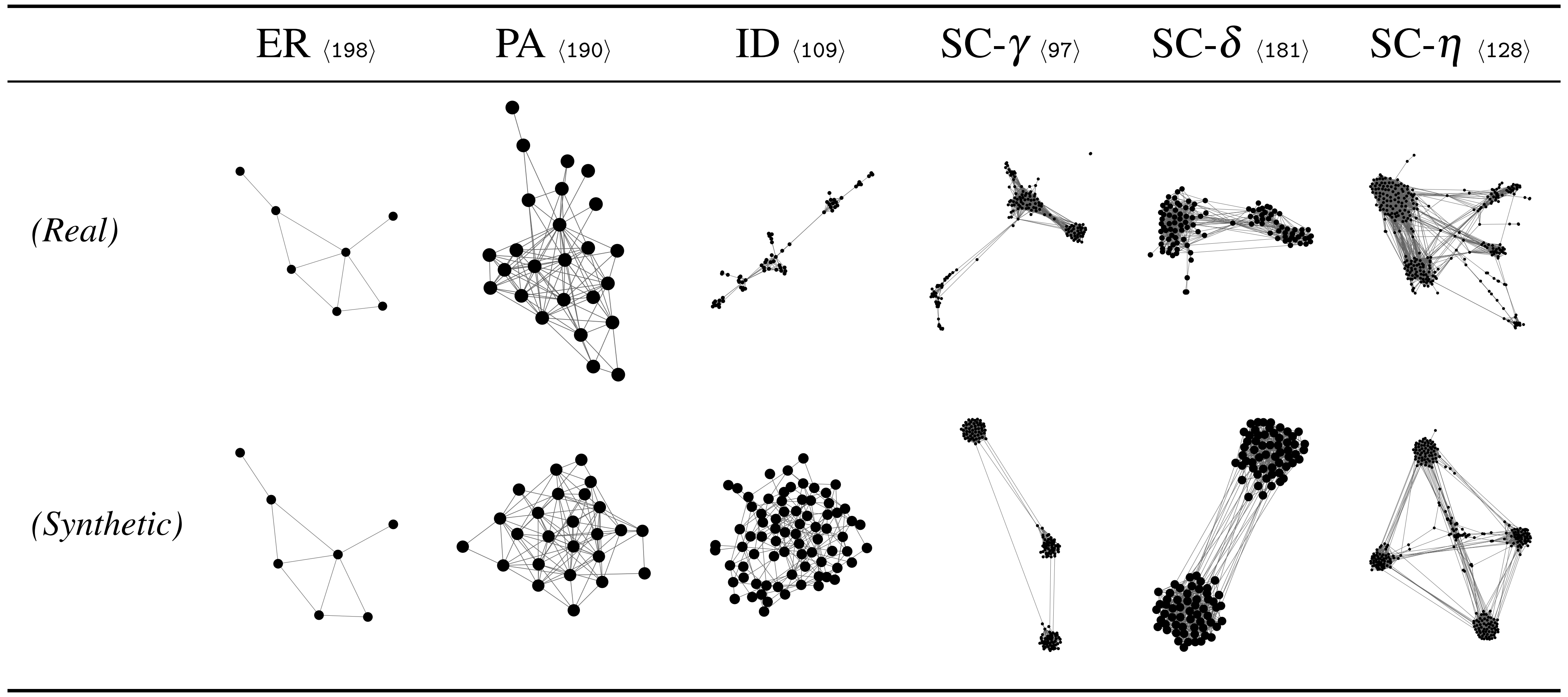
In-group linking behavior

topological factors only:
α, β, γ and θ

exogenous factors only:
δ

combination of both:
ε, ζ and η

SOCIAL CIRCLE (SC) GENOTYPES



Visual representation of some empirical ego-networks (top row) with their reconstruction (bottom row), for a selection of evoked families. ER, PA and ID are featured; each of the three main subfamilies of SC are also present (generators 97, 181 and 128 are all based on an affinity function of parameters 3, 2 and 5, respectively).

In-group linking behavior

topological factors only:
α, β, γ and θ

exogenous factors only:
δ

combination of both:
ε, ζ and η

Family	List of generator functions and corresponding network number ⟨ID⟩					
ER c	0.08 ⟨14⟩	0.88 ⟨50⟩	0.95 ⟨78⟩	54.6 ⟨82⟩	0.62 ⟨108⟩	6.0 ⟨124⟩
	$(\max(k_i, i) = 0 \rightarrow 0, 0.63)$ ⟨198⟩					
ID i	i ⟨58⟩	i ⟨109⟩				
ID’ e^i	e^i ⟨18⟩	e^i ⟨139⟩				
PA k	k ⟨26⟩	k ⟨81⟩	k ⟨100⟩	k ⟨105⟩	k ⟨111⟩	k ⟨134⟩
	k ⟨145⟩	k ⟨170⟩	k ⟨227⟩			
PA’ $k_i^{k_j}$	${k_j}^{k_i}$ ⟨0⟩	$(\min(j, .66) > k_i \rightarrow j, e^{k_j})^{(\min((j=0, k_j, k_i), e^{k_j}))}$ ⟨47⟩				${k_i}^{k_j}$ ⟨193⟩
SC-α $\psi_g(k^s, c)$	$\psi_8(k_j^2, .62) - k_i$ ⟨69⟩		$\psi_7(k^3, 4)$ ⟨126⟩			
SC-β $\psi_g(e^k, > \frac{1}{2})$	$\psi_3(2^k, .48)$ ⟨3⟩	$\psi_9(e^{k_i}, .49)$ ⟨36⟩	$\psi_4(e^k, 1.1)$ ⟨39⟩	$\psi_5(\frac{e^{\max(k_i, k_j)}}{k_i}, k_i)$ ⟨80⟩		$\psi_5(e^k, 1)$ ⟨90⟩
	$\psi_4(e^k, 1)$ ⟨110⟩	$\psi_8(e^k, d)$ ⟨138⟩	$\psi_4(k_i, .67)^{k_i}$ ⟨153⟩	$\psi_5(e^k, 1.7)$ ⟨213⟩	$\psi_3(e^k, 2)$ ⟨224⟩	
SC-γ $\psi_g(k^B, \sim 0)$	$\psi_9(k^k, 0)$ ⟨23⟩	$\psi_6(3^k, 0)$ ⟨31⟩	$\psi_4(4 \cdot k^5, 0)$ ⟨41⟩	$\psi_8(k^k, 0)$ ⟨57⟩	$\psi_3(e^{k_i + k_j}, .05)$ ⟨97⟩	
	$\psi_3(e^k, 0)$ ⟨104⟩	$\psi_3(2^k, 0)$ ⟨127⟩	$\psi_6(e^{\psi_5(1,k)}, 0) + .07$ ⟨141⟩		$\psi_7(e^k, 0)$ ⟨155⟩	$\psi_4(e^k, .06)$ ⟨157⟩
	$\psi_2(k_i \cdot e^{k_j}, 0)$ ⟨164⟩	$\psi_4(e^k, 0)$ ⟨177⟩	$\psi_5(k^7, .01)$ ⟨235⟩	$\psi_5(e^k, .03)$ ⟨236⟩		
SC-δ $\psi_g(e^i, *)$	$\psi_4(e^i, e^{k_i})$ ⟨6⟩	$\psi_4(i^j, k_j)$ ⟨89⟩	$\psi_2(j^i, k_i)$ ⟨92⟩	$\psi_3(e^i, k_i)$ ⟨121⟩	$\psi_3(e^i, e^7)$ ⟨137⟩	$\psi_3(e^i, 1)$ ⟨148⟩
	$\psi_2(9^i, 9^9)$ ⟨181⟩	$\psi_3(e^i, j)$ ⟨184⟩	$\psi_3(e^{i+j-d}, e^5)$ ⟨196⟩		$\psi_4(9^i, 9)$ ⟨202⟩	
SC-ε $\psi_g(ik, *)$	$9\psi_3(ik_i, 2k_i)$ ⟨9⟩	$\psi_4(ik_j, 6k_j)$ ⟨24⟩	$\psi_5(jk_j, k_j)$ ⟨25⟩	$\psi_9(ik_i, .1k_i)$ ⟨37⟩	$\psi_2(jk_j, k_j)$ ⟨75⟩	$\psi_7(jk_j, 7k_j)$ ⟨91⟩
	$\psi_6(ik_i, .44k_i)$ ⟨106⟩	$\psi_4(jk_i, .38)$ ⟨107⟩	$\psi_3(jk_i, k_j)$ ⟨115⟩	$\psi_4(i\log(k_i), 0)$ ⟨165⟩		$\psi_3(jk_i, \frac{k_i}{4})$ ⟨166⟩
	$(\frac{k_j k_i}{.66} + d)\psi_4(j, .61)$ ⟨188⟩		$\psi_3(ik_j, 2k_j)$ ⟨194⟩	$\psi_3(ik_j, k_j)$ ⟨206⟩	$\psi_3(ik_i, 0)$ ⟨209⟩	$\psi_4(ik_i, 3k_i)$ ⟨218⟩
SC-ζ $\psi_g(i^k, *)$	$\psi_7(i, 0)^{k_j}$ ⟨68⟩	$\frac{7}{d}\psi_4(i^{k_i}, .48)$ ⟨93⟩	$\psi_4(\frac{i^{k_j}}{k_j}, .18)$ ⟨95⟩	$\psi_8(i^{k_i}, 2)$ ⟨125⟩	$\psi_4(i^{k_i}, 0)$ ⟨156⟩	$\psi_4(\frac{1}{6}i^{k_i}, d)$ ⟨179⟩
	$\psi_9(dj^{k_i}, 0)$ ⟨185⟩	$\psi_{\min(i,4)}(i^{k_i}, 0)$ ⟨195⟩		$\psi_5(9j^{k_i}, .03)$ ⟨219⟩		
SC-η $\psi_g(ik^2, *)$	$\psi_5((ik_i)^2, i)$ ⟨16⟩	$\psi_5(ik_i{}^2, 6)$ ⟨128⟩	$\psi_4(2980.96k^2, 2k)$ ⟨132⟩		$\psi_2(ik_j{}^2, k_j{}^2)$ ⟨163⟩	
	$\psi_7(\psi_i(.5, k_j{}^2), 0)$ ⟨182⟩					
SC-θ $\psi_g(k, 0) - 1$	$\psi_4(k, 0) - .99$ ⟨8⟩		$\psi_7(k, 0) - .93$ ⟨83⟩			

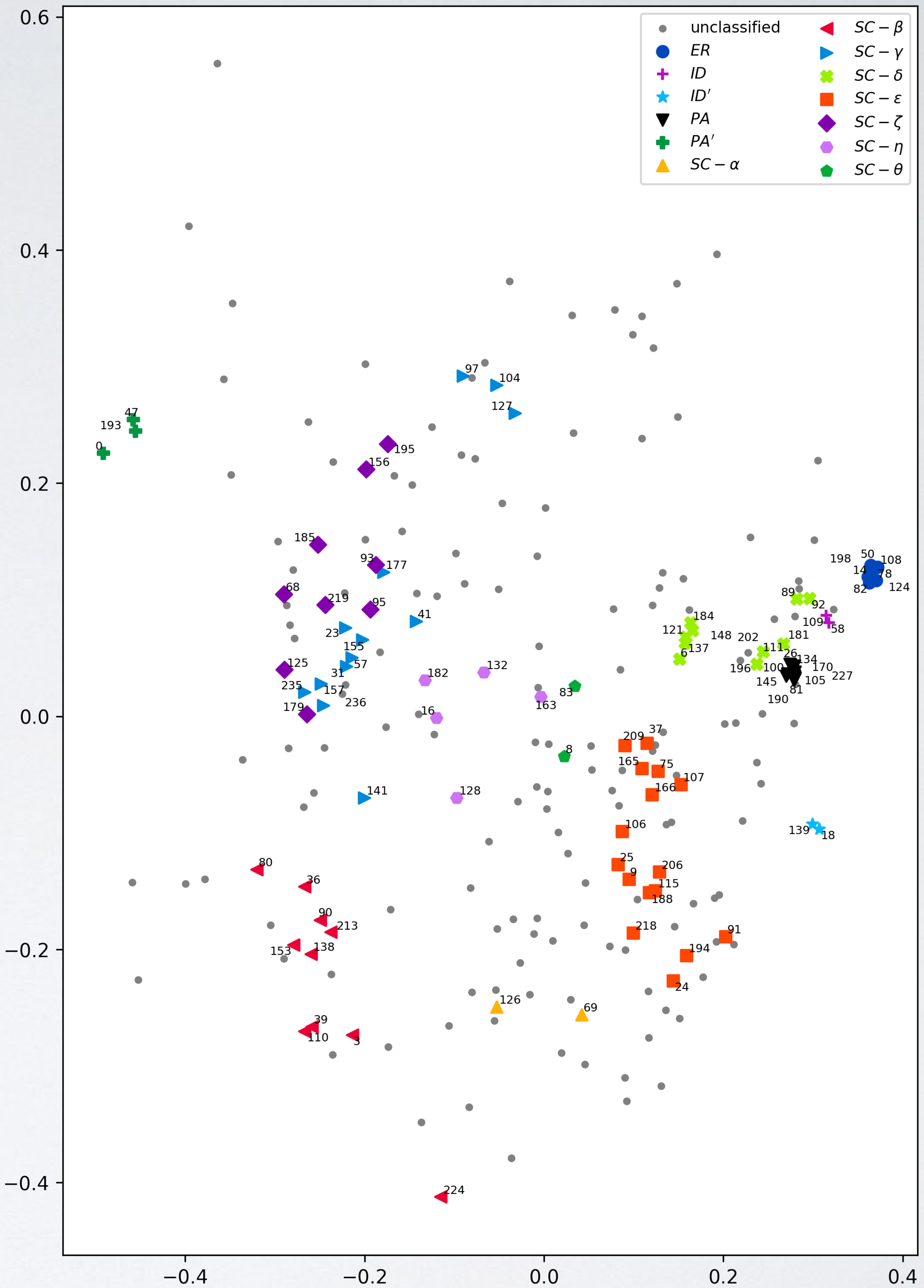


Fig. 3 Network generators mapped into a two-dimensional layout according to their pairwise distances. Different colors and shapes indicate families of generators that were manually identified as semantically similar. The legend shows the pattern that identifies each family.

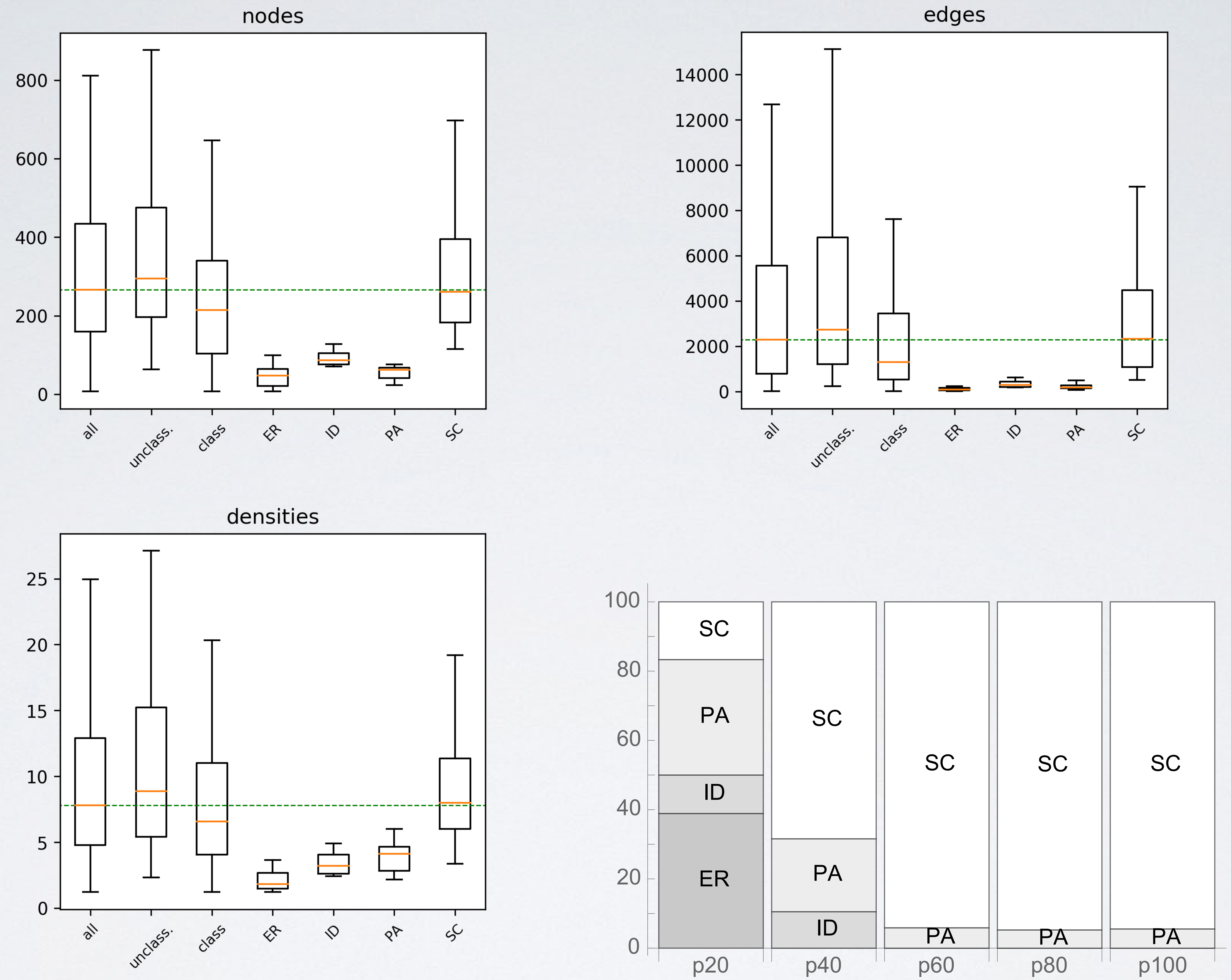


Fig. 4 *Top panel, and bottom-left:* Boxplots of numbers of nodes, edges and densities for the underlying networks of the various families, as well as all, unclassified and classified. Horizontal dashed line indicates overall median. *Bottom-right:* Stacked plot of family ratio per percentile of network density.

TAKE-HOME MESSAGE

- Propose an artificial scientist to guide hypothesis search
- Decipher the genotype of networks from their phenotype

TAKE-HOME SOFTWARE

- Synthetic open-source tool
- https://github.com/telmomenezes/synthetic

THANKS !

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