AUTOMATIC DISCOVERY OF FAMILIES OF NETWORK GENERATIVE PROCESSES

Telmo MENEZES

menezes@cmb.hu-berlin.de





Camille ROTH

roth@cmb.hu-berlin.de



cmb.huma-num.fr



SOCIAL NETWORK FAMILIES

APPROACH

Automatic discovery of network generation laws

Menezes, Roth, 2014



nature.com/articles/srep06284





ANR Algopol, 2012-16

FIELD

Facebook egocentered friendship networks

GOAL

Network classification according to their genotype

Menezes, Roth, 2019

pringer Proceedings in Complexity

Fakhteh Ghanbarnejad Rishiraj Saha Roy Fariba Karimi Jean-Charles Delvenne Bivas Mitra Editors

Dynamics On and Of Complex Networks III

Machine Learning and Statistical **Physics Approaches**

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)







bottom-up evaluation of the tree



Evolutionary algorithm iteratively improves generator



Evolutionary algorithm iteratively improves generator

Random generator:





Evolutionary algorithm iteratively improves generator





Evolutionary algorithm iteratively improves generator





DISCOVERED GENOTYPES

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

Word adjacencies

 $W \equiv$



k, yet not too far





(data: Adamic & Glance, 2005)

(data: Newman, 2006)

Political blogs

Facebook

$$w = \mathbf{\Psi}(3, i.k, k)$$

3 groups, local PA



(data: Leskovec & Mc Auley, 2012)

$$exp(4-2d)$$

close

DISCOVERED GENOTYPES

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



(data: Newman, 2006)

(data: Adamic & Glance, 2005)

Political blogs

$$exp(4-2d)$$

close



Facebook

$$w = \mathbf{\Psi}(3, i.k, k)$$

3 groups, local PA



(data: Leskovec & Mc Auley, 2012)



NETWORK CLASSIFICATION ACCORDING TO GENOTYPE

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

Cat brain: cortical/thalmic Les Miserables Macaque brain: visual cortex 2 Macaque brain: visual/sensory cortex Unionization in a hi-tech firm Zachary karate club US political books co-purchase Dolphins Protein: oxidoreductase (1AOR) Communication within a sawmill on strike BA: (100,2) Phanerochaete velutina control 11-2 Biogrid: *R. norvegicus* Electronic circuit (s208) 2008 NCAA Football Schedule



GOAL



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





FACEBOOK EGO-CENTERED FRIENDSHIP NETWORKS



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

E. contact@app.algopol.fr Site du projet : algopol.fr

Tenez-vous au courant des dernières évolutions d'Algopol Ce projet de recherche est soutenu par l'ANR.



"Algopol" application



FACEBOOK EGO-CENTERED FRIENDSHIP NETWORKS







FACEBOOK EGO-CENTERED FRIENDSHIP NETWORKS





Family	List of generator functions and corresponding network number (ID)							
	0.08	0.88	0.95	54.6	0.62	6.0		
ER	$\langle 14 \rangle$	(50)	(78)	$\langle 82 \rangle$	(108)	(124)		
C	$(\max(k_i, i) =$	$= 0 \to 0, 0.63)$						
	$\langle 198 \rangle$							
(D	i	i						
	<pre><58></pre>	(109)						
(D'	e^i	e^i						
e^i	$\langle 18 \rangle$	(139)						
	k	k	k	k	k	k		
PA	(26)	$\langle 81 \rangle$	$\langle 100 \rangle$	(105)	$\langle 111 \rangle$	(134)		
k	k	k	k					
	(145)	$\langle 170 \rangle$	(227)					
PA'	$k_i^{k_i}$	(min(<i>i</i> 66)	$> k_i \rightarrow i.e^{k_j}$)(min(($j=0,k$)	$_{j},k_{i}),e^{k_{j}}))$	$k_i^{k_j}$		
k_j	$\langle 0 \rangle$	$\langle 47 \rangle$, , , , , , , , , , , , , , , , , , ,)		<pre>(193)</pre>		
SC-α	$\psi_8(k_j^2,.62)$ -	$-k_i$	$\psi_7(k^3, 4)$					
$\psi_g(k^s,c)$	(69)		(126)					
	$W_{2}(2^{k} 48)$	$W_0(e^{k_i} 49)$	$u_{I}(e^{k} 1 1)$	$M_{\tau} \left(\frac{e^{\max(k_i)}}{k_i} \right)$	$\frac{k_j}{k_j}$ k:	$W_{5}(e^{k} 1)$		
SC-R	Ψ3(2,)		ψ 4(ψ , 1 , 1)	$\Psi \mathcal{I} (k_i)$,~()	$\psi_{\mathcal{I}}(\mathcal{C},\mathbf{I})$		
$\sum p$	$(a^k 1)$	(30)	$\frac{1}{k_i}$	$\frac{1}{2} \left(\frac{k}{k} \right)^{-1}$	7) $u_{\alpha}(a^{k} 2)$	(90)		

Family	List of generator functions and corresponding network number (ID)						
ER C	0.08 $\langle 14 \rangle$ $(\max(k_i, i) =$ $\langle 198 \rangle$	0.88 (50) $= 0 \rightarrow 0, 0.63$	0.95 (78)	54.6 (82)	0.62 <108>	6.0 (124)	
ID i	<i>i</i> (58)	<i>i</i> <109>					
ID ' e^i	e^{i} <pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<i>eⁱ</i> <139>					
PA k	k <26> k <145>	k <81> k <170>	k <100> k <227>	k <105>	k <111>	k <134>	
PA' $k_i^{k_j}$	$k_j^{k_i}$	$(\min(j,.66)$	$> k_i \rightarrow j, e^{k_j}$)(min(($j=0,k$)	$_{j},k_{i}),e^{k_{j}}))$	$k_i^{k_j}$ (193)	
SC- α $\psi_g(k^s,c)$	$\psi_8(k_j^2,.62)$ -	$-k_i$	ψ 7(k ³ ,4)				
SC- β	$\psi_3(2^k, .48)$	$\psi_9(e^{k_i}, .49)$ (36)	$\psi_4(e^k, 1.1)$ (39)	$\psi_{5}\left(\frac{e^{\max(k_{i})}}{k_{i}}\right)$ (80) $i W_{5}\left(e^{k} + 1\right)$	$(e^{k_j}), k_i$	$\psi_5(e^k,1)$	

Family	List of generator functions and corresponding network number $\langle ID \rangle$							
ER C	0.08 $\langle 14 \rangle$ $(\max(k_i, i) =$ $\langle 198 \rangle$	0.88 (50) $= 0 \rightarrow 0, 0.63$	0.95 (78)	54.6 (82)	0.62 <108>	6.0 (124)		
ID i	i (58)	<i>i</i> <109>		nitut in an	an in the Company of the Constant of the Const	an the second second second		
ID ' e^i	e^i <pre>(18)</pre>	<i>eⁱ</i> <139>	NOT THE ADDRESS AND AND AND ADDRESS AND ADDRESS					
PA k	k <26> k <145>	k (81) k (170)	k <100> k <227>	k <105>	k <111>	k <134>		
PA' $k_i^{k_j}$	$k_j^{k_i}$	$(\min(j,.66)$	$> k_i \rightarrow j, e^{k_j}$	$(j)(\min((j=0,k))$	$(k_j,k_i),e^{k_j}))$	$k_i^{k_j}$ <193>		
SC- α $\psi_g(k^s,c)$	$\psi_8(k_j^2,.62)$ -	$-k_i$	ψ 7(k ³ ,4)					
SC- β	$\psi_3(2^k, .48)$	$\psi_9(e^{k_i}, .49)$ (36)	$\psi_4(e^k, 1.1)$ (39)	$\Psi_5\left(\frac{e^{\max(k)}}{k_i}\right)$ (80)	$(k_{i},k_{j}), k_{i})$	$\psi_5(e^k,1)$		

Family	List of generator functions and corresponding network number (ID)						
	0.08	0.88	0.95	54.6	0.62	6.0	
ER	$\langle 14 \rangle$	(50)	(78)	<pre><82></pre>	$\langle 108 \rangle$	(124)	
С	$(\max(k_i, i) =$	$= 0 \to 0, 0.63)$					
	$\langle 198 \rangle$						
ID	i	i					
i	$\langle 58 \rangle$	$\langle 109 \rangle$					
ID'	e^i	e^i					
e^i	$\langle 18 \rangle$	(139)					
S. C.	k	k	k	k	k	k	
PA	<pre>(26)</pre>	$\langle 81 \rangle$	$\langle 100 \rangle$	(105)	$\langle 111 \rangle$	$\langle 134 \rangle$	
k	k	k	k				
	(145)	$\langle 170 \rangle$	(227)				
PA'	$k : k_i$	$(\min(i 66))$	$> k \rightarrow i e^{k_j}$	$\sum_{j=0,k}$	$_{j},k_{i}),e^{k_{j}}))$	$k_{j}^{k_{j}}$	
$k_{j}^{k_{j}}$	$\langle 0 \rangle$	$\langle 47 \rangle$	$> n_l + j, c$)		<pre>////////////////////////////////////</pre>	
	And and a second s						
SC-α	$\psi_8(k_j^2,.62)$ -	$-k_i$	$\psi_7(k^3,4)$				
$\psi_g(k^s,c)$	$\langle 69 \rangle$		(126)				
	$W_2(2^k 48)$	$W_0(e^{k_i} 49)$	$W_{1}(e^{k} 1 1)$	$W_{5}(e^{\max(k_{l})})$	(k_j) (k_i)	$W_{5}(e^{k} 1)$	
SC-B	(3)	(36)	(39)	r_{20}	,,	(00)	
	(3)	(30)	(3)	(00)	$(k \circ)$	(90)	

$SC-\alpha \\ \psi_g(k^s,c)$	$\psi_8(k_j^2,.62) - $	k _i	$\psi_7(k^3,4)$			
SC- β $\psi_g(e^k, > \frac{1}{2})$	$egin{aligned} &\psi_3(2^k,.48)\ ^{\scriptscriptstyle \langle 3 angle} &\psi_4(e^k,1)\ ^{\scriptscriptstyle \langle 110 angle} \end{aligned}$	$\psi_9(e^{k_i},.49)$ (36) $\psi_8(e^k,d)$ (138)	$egin{aligned} & \psi_4(e^k,1.1) \ & {\scriptstyle \langle39 angle} \ & \psi_4(k_i,.67)^{k_i} \ & {\scriptstyle \langle153 angle} \end{aligned}$	$\psi_5(rac{e^{\max(k_i,k_j)}}{k_i}, rac{1}{\sqrt{80}})$ $\psi_5(e^k, 1.7)$ $\langle 213 angle$	$k_i) \ \psi_3(e^k,2) \ {}_{\langle 224 angle}$	$\psi_5(e^k,1)$
$\frac{\mathbf{SC-\gamma}}{\psi_g(k^B,\sim 0)}$	$egin{aligned} & \psi_9(k^k,0) \ & {}^{\langle 23 angle} & \psi_3(e^k,0) \ & {}^{\langle 104 angle} & \psi_2(k_i \cdot e^{k_j},0) \ & {}^{\langle 164 angle} & \langle 164 angle \end{aligned}$	$\psi_{6}(3^{k},0)$ (31) $\psi_{3}(2^{k},0)$ (127) $\psi_{4}(e^{k},0)$ (177)	$\psi_4(4 \cdot k^5, 0)$ $\langle 41 \rangle$ $\psi_6(e^{\psi_5(1,k)}, 0)$ $\langle 141 \rangle$ $\psi_5(k^7, .01)$ $\langle 235 \rangle$	$egin{aligned} & \psi_8(k^k,0)\ & \ & \ & \ & \ & \ & \ & \ & \ & \ &$	$\psi_3(e^{k_i+k_j},.05)$	5) $\psi_4(e^k,.06)$
\mathbf{SC} - δ $\psi_g(e^i,*)$	$egin{aligned} & \psi_4(e^i,e^{k_i}) \ & {}^{\scriptscriptstyle \langle 6 angle} \ & \psi_2(9^i,9^9) \ & {}^{\scriptscriptstyle \langle 181 angle} \end{aligned}$	$egin{aligned} & \psi_4(i^j,k_j) \ & {}^{\scriptscriptstyle (89 angle} \ & \psi_3(e^i,j) \ & {}^{\scriptscriptstyle (184 angle} \end{aligned}$	$egin{aligned} & \psi_2(j^i,k_i) \ & {}^{\langle92 angle} \ & \psi_3(e^{i+j-d},e^{5d}) \ & {}^{\langle196 angle} \end{aligned}$	$\psi_3(e^i,k_i)$	$egin{aligned} &\psi_3(e^i,e^7)\ &\langle^{137 angle}\ &\psi_4(9^i,9)\ &\langle^{202 angle} \end{aligned}$	$\psi_3(e^i,1)$
\mathbf{SC} - $arepsilon$ $\psi_g(ik,*)$	9 $\psi_3(ik_i,2k_i)$ (9) $\psi_6(ik_i,.44k_i)$ (106)	$\psi_4(ik_j,6k_j)$ $\langle 24 \rangle$ $\psi_4(jk_i,.38)$ $\langle 107 \rangle$	$\psi_5(jk_j,k_j)$ $\langle 25 \rangle$ $\psi_3(jk_i,k_j)$ $\langle 115 \rangle$	$\psi_{9}(ik_{i},.1k_{i})$ (37) $\psi_{4}(i\log(k_{i}),0)$	$\psi_2(jk_j,k_j)$ (75) (75)	$ \psi_7(jk_j,7k_j) $ $ \langle 91 \rangle $ $ \psi_3(jk_i,\frac{k_i}{4}) $
	$(rac{k_jk_i}{.66}+d)\psi_4($	<i>j</i> ,.61)	$\psi_3(ik_j,2k_j)$	$\langle 103 \rangle$ $\psi_3(ik_j,k_j)$ $\langle 206 \rangle$	$\psi_3(ik_i,0)$	$\langle 186\rangle$ $\psi_4(ik_i, 3k_i)$ $\langle 218\rangle$
\mathbf{SC} - $\boldsymbol{\zeta}$ $\boldsymbol{\psi}_{g}(i^{k},*)$	$(rac{k_{j}k_{i}}{.66}+d)\psi_{4}(y_{188})$ $\psi_{7}(i,0)^{k_{j}}$ $\langle 68 \rangle$ $\psi_{9}(dj^{k_{i}},0)$ $\langle 185 \rangle$	$j,.61)$ $rac{7}{d} \psi_4(i^{k_i},.48)$ (93) $\psi_{\min(i,4)}(i^{k_i},0)$ (195)	(123) $\psi_{3}(ik_{j},2k_{j})$ (194) $\psi_{4}(\frac{i^{k_{j}}}{k_{j}},.18)$ (95) (95)	$(103) \\ \psi_{3}(ik_{j},k_{j}) \\ (206) \\ \psi_{8}(i^{k_{i}},2) \\ (125) \\ \psi_{5}(9j^{k_{i}},.03) \\ (219) \\ (100) \\ (219) \\ (210) \\ (100) \\ ($	$\psi_3(ik_i,0)$ 209 $\psi_4(i^{k_i},0)$ (156 ψ	$\psi_{4}(ik_{i}, 3k_{i})$ (218) $\psi_{4}(\frac{1}{6}i^{k_{i}}, d)$ (179)
SC- ζ $\psi_g(i^k, *)$ SC- η $\psi_g(ik^2, *)$	$(\frac{k_{j}k_{i}}{.66} + d)\psi_{4}(a_{(188)})$ $\psi_{7}(i,0)^{k_{j}}(68)$ $\psi_{9}(d j^{k_{i}},0)$ (185) $\psi_{5}((ik_{i})^{2},i)$ (16) $\psi_{7}(\psi_{i}(.5,k_{j}^{2}))$ (182)	j,.61) $\frac{7}{d} \psi_4(i^{k_i},.48)$ $\langle 93 \rangle$ $\psi_{\min(i,4)}(i^{k_i}, 0)$ $\langle 195 \rangle$ $\psi_5(ik_i^2, 6)$ $\langle 128 \rangle$),0)	$\psi_{3}(ik_{j}, 2k_{j})$ (194) $\psi_{4}(\frac{i^{k_{j}}}{k_{j}}, .18)$ (95) $\psi_{4}(2980.96k)$ (132)	$(103) \psi_{3}(ik_{j},k_{j}) (206) \psi_{8}(i^{k_{i}},2) (125) \psi_{5}(9j^{k_{i}},.03) (219) c^{2},2k)$	$\psi_{3}(ik_{i},0)$ (209) $\psi_{4}(i^{k_{i}},0)$ (156) $\psi_{2}(ik_{j}^{2},k_{j}^{2})$ (163)	$\psi_{4}(ik_{i}, 3k_{i})$ (218) $\psi_{4}(\frac{1}{6}i^{k_{i}}, d)$ (179)

SOCIAL CIRCLE (SC) GENOTYPES

In-group linking behavior

topological factors only: α, β, γ and θ

exogenous factors only: δ

combination of both: ϵ, ζ and η



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).

SOCIAL CIRCLE (SC) GENOTYPES

In-group linking behavior

topological factors only: α, β, γ and θ

exogenous factors only: δ

combination of both: ϵ, ζ and η

Family	<i>List of generator functions and corresponding network number</i> (ID)							
	0.08	0.88	0.95	54.6	0.62	6.0		
ER	(14)	(50)	(78)	(82)	(108)	(124)		
С	$(\max(k_i,i) = {}^{\langle 198 angle}$	$0 \to 0, 0.63)$						
ID	i	i						
1	(58)	(109)						
ID'	e^{i}	e^{i}						
e^{i}	(18)	(139)						
D.	k	k	k	k	k	k		
PA k	(26) I z	(81) Iz	(100) b	(105)	$\langle 111 \rangle$	(134)		
ĸ	K (145)	κ (170)	K (227)					
	1.			(min((: 01 1)	$k_{i \lambda \lambda}$	1.		
$\mathbf{PA'}_{k}$	$k_j^{\kappa_i}$	$(\min(j,.66))$	$> k_i \rightarrow j, e^{\kappa_j}$	$(\min((j=0,\kappa_j,\kappa_i)),$	<i>e</i> ,))	$k_i^{\kappa_j}$		
$k_i^{\kappa_j}$	(0)	(47)				(193)		
SC-α	$\psi_8(k_j^2,.62) -$	<i>k</i> _i	$\psi_7(k^3,4)$					
$\Psi_g(k^s,c)$	(69)		(126)					
	$\psi_3(2^k,.48)$	$\Psi_9(e^{k_i},.49)$	$\Psi_4(e^k, 1.1)$	$\Psi_5\left(\frac{e^{\max(k_i,k_j)}}{k_i}\right)$	k_i)	$\Psi_5(e^k,1)$		
SC- β	(3)	(36)	(39)	(80)	• /	(90)		
$\psi_g(e^k, > \frac{1}{2})$	$\psi_4(e^k,1)$	$\psi_8(e^k,d)$	$\psi_4(k_i,.67)^{k_i}$	$\psi_5(e^k, 1.7)$	$\psi_3(e^k,2)$			
	(110)	(138)	(153)	(213)	(224)			
	$\psi_9(k^k,0)$	$\psi_6(3^k,0)$	$\psi_4(4\cdot k^5,0)$	$\psi_8(k^k,0)$	$\psi_3(e^{k_i+k_j},.0)$	5)		
	$\langle 23 \rangle$	$\langle 31 \rangle$	$\langle 41 \rangle$	(57)	(97)			
SC- γ	$\psi_3(e^{\kappa},0)$	$\psi_3(2^{\kappa},0)$	$\psi_6(e^{\psi_5(1,k)},0)$	(0) + .07	$\psi_7(e^{\kappa},0)$	$\psi_4(e^{\kappa},.06)$		
$\Psi_g(k^D,\sim 0)$	$\langle 104 \rangle$	$\langle 127 \rangle$	$\langle 141 \rangle$	$W_{\tau}(e^k \mid 03)$	(155)	(157)		
	$\langle 164 \rangle$	$\psi_4(c, 0)$	$\langle 235 \rangle$	φ3(C ,.05) (236)				
	$W_{4}(e^{i} e^{k_{i}})$	$W_{4}(i^{j} k_{i})$	$W_2(i^i k_i)$	$W_2(e^i k_i)$	$W_2(e^i e^7)$	$W_2(e^i 1)$		
SC- δ	$\langle 6 \rangle$	(89)	$\langle 92 \rangle$	(121)	(137)	$\langle 148 \rangle$		
$\psi_g(e^i,*)$	$\psi_2(9^i,9^9)$	$\psi_3(e^i,j)$	$\psi_3(e^{i+j-d},e$	5)	$\psi_4(9^i,9)$			
	(181)	(184)	(196)		(202)			
	$9\psi_3(ik_i,2k_i)$	$\psi_4(ik_j,6k_j)$	$\psi_5(jk_j,k_j)$	$\psi_9(ik_i,.1k_i)$	$\psi_2(jk_j,k_j)$	$\psi_7(jk_j,7k_j)$		
SC c	$\langle 9 \rangle$	$\langle 24 \rangle$	$\langle 25 \rangle$	$\langle 37 \rangle$	(75) ()	$\langle 91 \rangle$		
$W_{\alpha}(ik,*)$	$\Psi_6(\iota\kappa_i, .44\kappa_i)$	$\psi_4(J\kappa_i,,\omega_i)$	$\psi_3(J\kappa_i,\kappa_j)$	$\psi_4(\iota \log(\kappa_i), \psi_{(165)})$	0)	$\Psi_3(J\kappa_i, \frac{1}{4})$		
rg(,)	$\left(\frac{k_j k_i}{k_i} + d\right) \Psi_4$	<i>i</i> 61)	$\Psi_3(ik_i, 2k_i)$	$\Psi_3(ik_i,k_i)$	$\Psi_3(ik_i,0)$	$\Psi_4(ik_i, 3k_i)$		
	(188)	J) -)	(194)	(206)	(209)	(218)		
	$\Psi_7(i,0)^{k_j}$	$\frac{7}{4}\psi_4(i^{k_i}48)$	$\Psi_4(\frac{i^{k_j}}{l}18)$	$\Psi_8(i^{k_i},2)$	$\Psi_4(i^{k_i},0)$	$\Psi_4(\frac{1}{\epsilon}i^{k_i}.d)$		
SC-Z	(68)	(93)	$\langle 95 \rangle$	(125)	(156)	(179)		
$\psi_g(i^k,*)$	$\psi_9(dj^{k_i},0)$	$\psi_{\min(i,4)}(i^{k_i},0)$))	$\psi_5(9j^{k_i},.03)$				
	(185)	(195)		(219)				
	$\psi_5((ik_i)^2,i)$	$\psi_5(ik_i^2,6)$	$\psi_4(2980.96)$	$(k^2, 2k)$	$\Psi_2(ik_j^2,k_j^2)$			
SC-η	(16)	(128)	(132)		(163)			
$\psi_g(ik^2,*)$	$\psi_7(\psi_i(.5,k_j^2))$),0)						
	(182)					1. 1. 1.		
SC-θ	$\psi_4(k,0)99$)	$\psi_7(k,0)9$	03				
$\Psi_g(k,0)-1$	$\langle 8 \rangle$		(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

Telmo MENEZES

menezes@cmb.hu-berlin.de



Digital Humanities

Computational Social Sciences

cmb.huma-num.fr/job-offers

TAKE-HOME SOFTWARE

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

THANKS !

Camille ROTH

roth@cmb.hu-berlin.de





European Research Council Established by the European Commission

socsemics.huma-num.fr