

*Statistical Analysis of Networks*

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# Coevolution of Networks and Behavior

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# Motivating Example

Evaluating peer-influence processes in a prison-based therapeutic community: a dynamic network approach



Derek A. Kreager<sup>a,b,\*</sup>, David R. Schaefer<sup>c</sup>, Kimberly M. Davidson<sup>a</sup>, Gary Zajac<sup>b</sup>, Dana L. Haynie<sup>d</sup>, George De Leon<sup>e</sup>

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<sup>b</sup> *Criminal Justice Research Center, Pennsylvania State University, 211 Oswald Tower, University Park, PA 16802, USA*

<sup>c</sup> *Department of Sociology, University of California-Irvine, 3151 Social Sciences Plaza, Irvine, CA 92697, USA*

<sup>d</sup> *Department of Sociology, Ohio State University, 238 Townshend Hall, Columbus, OH 43210, USA*

<sup>e</sup> *New York University School of Medicine, 550 First Avenue, New York, NY, 10016, USA*

❖ What is a “therapeutic community”? What does it do?

# Motivating Example

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- ❖ If the causal mechanism hypothesized by the model is working, what should the network “look like”?

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- ❖ If the causal mechanism hypothesized by the model is working, what should the network “look like”?
- ❖ Homophily!!!

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# Motivating Example

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An engaged  
resident



Time  $t$

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# Motivating Example

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An engaged  
resident



A new  
resident

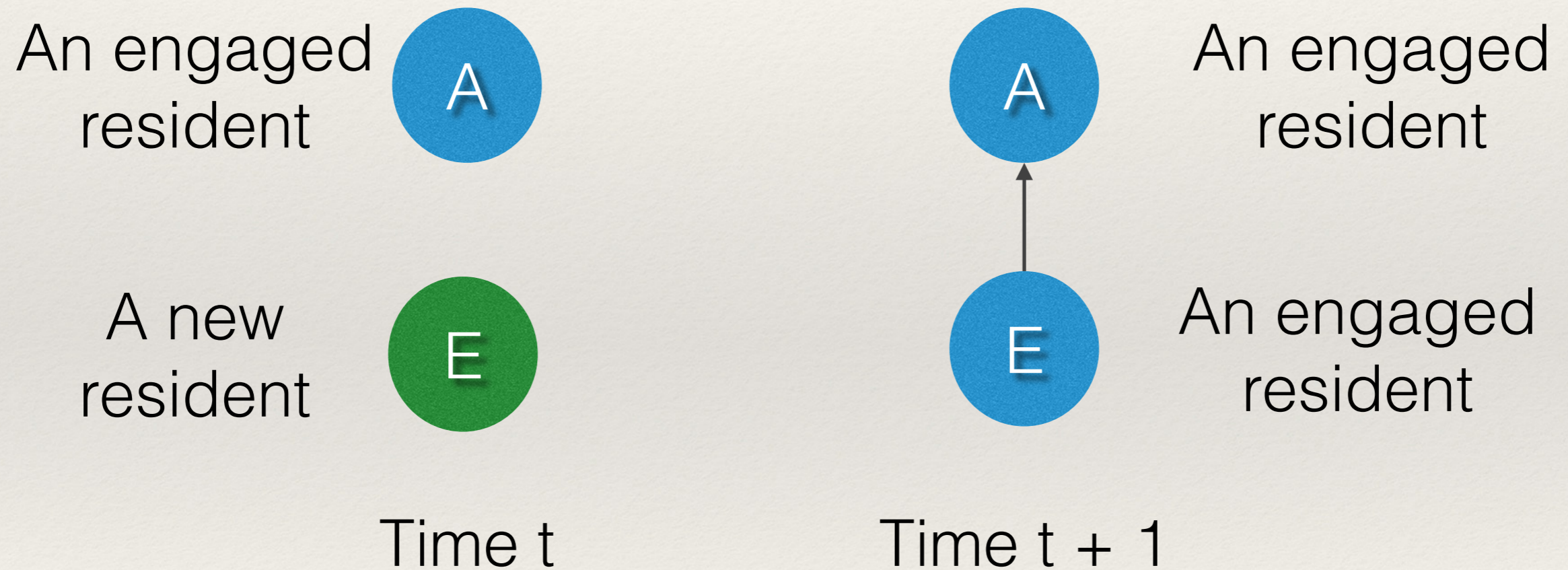


Time  $t$

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# Motivating Example

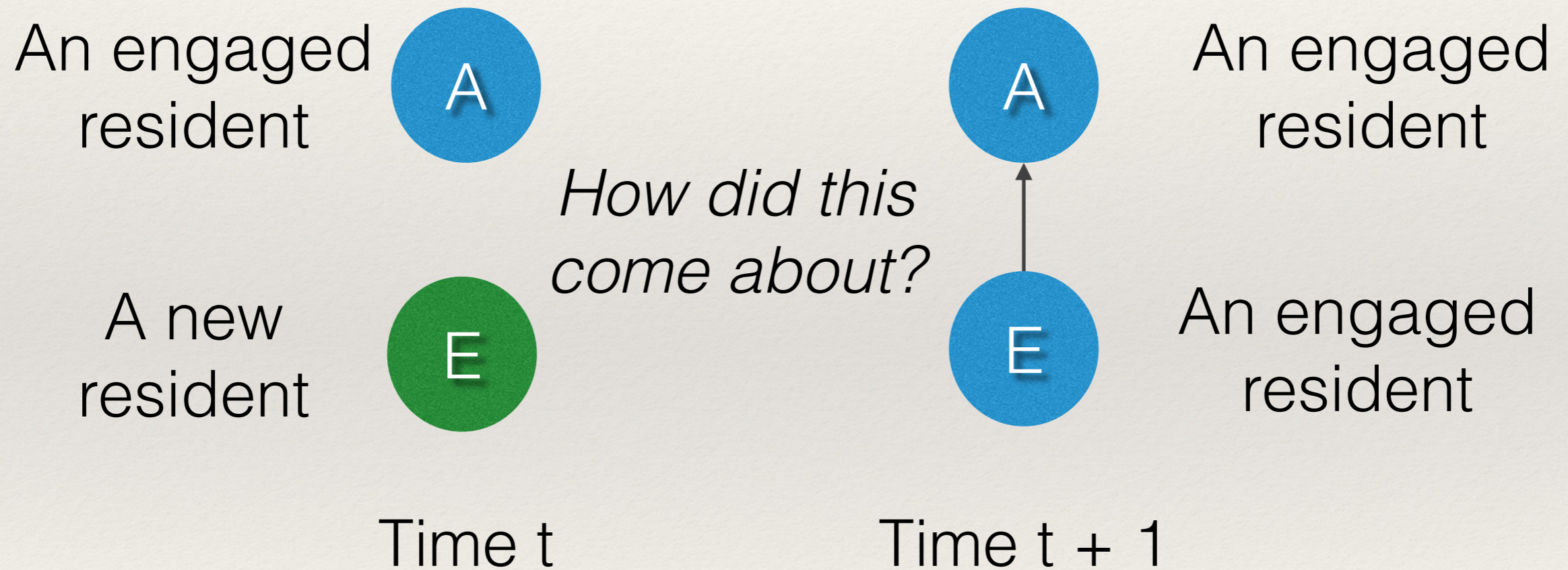
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# Motivating Example

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# Motivating Example

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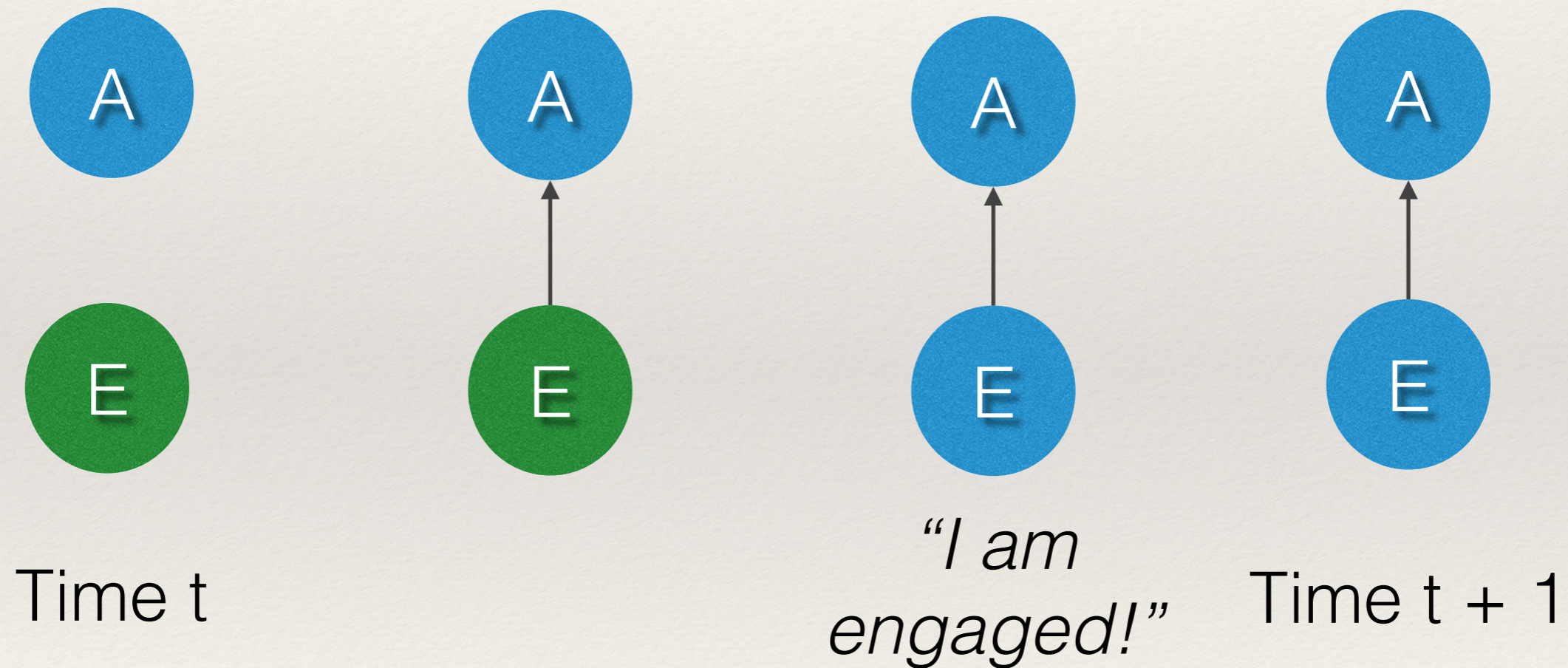
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- ❖ The basic problem is that **homophily** is an outcome that can be generated through three different mechanisms:
  - ❖ Selection
  - ❖ Influence
  - ❖ Cross-dimensional selection

# Motivating Example

*Social influence*

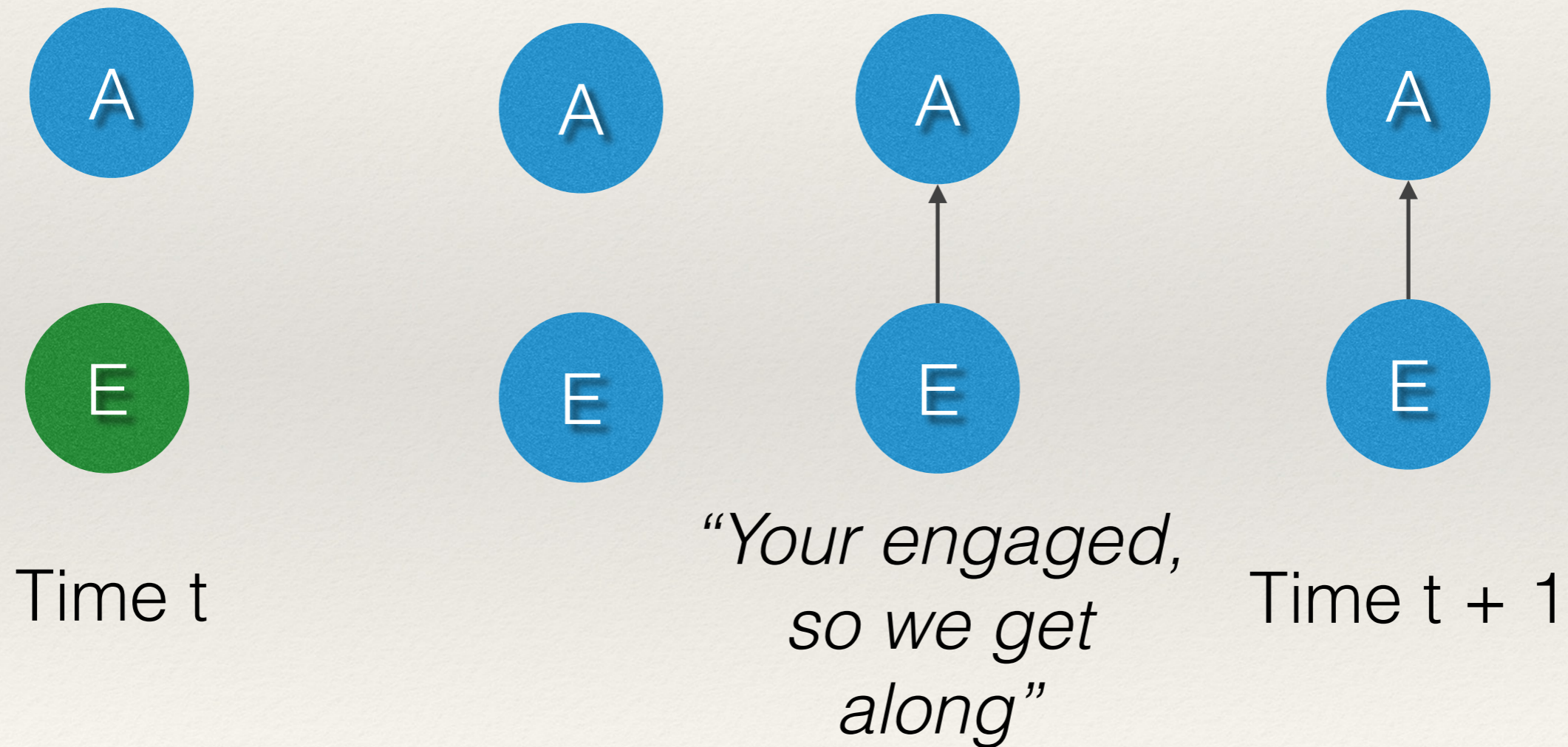


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# Motivating Example

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*Selection*



# Motivating Example

*Cross-Dimensional  
selection*



Time t



Time t + 1

*“You’re also a  
circle, we get  
along”*

# Motivating Example

**Table 1**  
Stochastic Actor-Oriented Models of Social Ties in a Prison Therapeutic Community.

Network Selection Function	M1			M2			M3			M4		
	b	(se)		b	(se)		b	(se)		b	(se)	
Rate (period 1)	16.95	***	(1.38)	16.06	***	(1.28)	17.26	***	(1.19)	14.49	***	(1.07)
Rate (period 2)	10.46	***	(0.76)	10.26	***	(0.86)	10.58	***	(0.77)	9.63	***	(0.74)
Rate (period 3)	9.28	***	(0.81)	9.34	***	(0.91)	9.38	***	(0.82)	8.56	***	(0.74)
Rate (period 4)	13.02	***	(1.12)	13.59	***	(1.41)	14.37	***	(1.18)	12.99	***	(1.13)
Rate (period 5)	15.60	***	(1.15)	15.89	***	(1.37)	16.65	***	(1.18)	14.64	***	(1.04)
Rate (period 6)	12.79	***	(0.96)	12.73	***	(1.01)	14.45	***	(1.07)	13.07	***	(1.06)
Rate (period 7)	12.88	***	(0.90)	13.18	***	(1.16)	14.11	***	(1.12)	13.12	***	(1.03)
Rate (period 8)	14.89	***	(1.09)	15.38	***	(1.24)	16.65	***	(1.30)	15.12	***	(1.17)
Rate (period 9)	12.66	***	(1.14)	12.59	***	(1.09)	13.70	***	(1.10)	12.66	***	(1.07)
Outdegree (density)	-.80	***	(0.03)	-1.43	***	(0.03)	-1.15	***	(0.05)	-1.67	***	(0.05)
Reciprocity				1.67	***	(0.09)				1.58	***	(0.09)
Transitive Triplets				.25	***	(0.02)				.29	***	(0.02)
Transitive Reciprocal Triplets				-.31	***	(0.05)				-.31	***	(0.05)
Same Race							.67	***	(0.05)	.53	***	(0.05)
Alter Age							-.009	***	(0.002)	-.007	***	(0.002)
Ego Age							.009	**	(0.004)	.009	***	(0.003)
Age Similarity							.87	***	(0.12)	.75	***	(0.11)
Alter Offense Gravity Score							.01		(0.01)	.01	†	(0.01)
Ego Offense Gravity Score							.03	*	(0.01)	.02	*	(0.01)
Offense Gravity Score Similarity							.14		(0.16)	.06		(0.15)
Alter TABE Score							.002	*	(0.001)	.001		(0.001)
Ego TABE Score							-.001		(0.001)	-.001		(0.001)
TABE Similarity							.24	***	(0.09)	.22	***	(0.09)
Alter TCU Score							.03		(0.02)	.01		(0.02)
Ego TCU Score							.08	*	(0.03)	.04		(0.03)
TCU Score similarity							.25	†	(0.14)	.16		(0.13)
Alter Time on Unit							-.001		(0.001)	-.005	***	(0.001)
Ego Time on Unit							-.008	***	(0.001)	-.010	***	(0.001)
Time on Unit Similarity							1.83	***	(0.11)	1.19	***	(0.12)
Alter Treatment Engagement	-.01		(0.03)	-.07	**	(0.03)	.07	*	(0.03)	-.001		(0.03)
Ego Treatment Engagement	.15	***	(0.03)	.09	***	(0.03)	.24	***	(0.04)	.16	***	(0.03)
Trtmt. Engagement Similarity	.46	***	(0.16)	.32	*	(0.14)	.22		(0.16)	.07		(0.16)
<i>Engagement Function</i>												
Rate (period 1)	.70	*	(0.34)	.68	**	(0.28)	.71	***	(0.25)	.71	***	(0.24)
Rate (period 2)	.74	**	(0.29)	.76	***	(0.29)	.76	**	(0.32)	.77	**	(0.30)
Rate (period 3)	.96	†	(0.51)	.97	**	(0.38)	.98	*	(0.44)	.98	**	(0.39)
Rate (period 4)	.63	*	(0.31)	.64	**	(0.26)	.65	***	(0.24)	.65	**	(0.25)
Rate (period 5)	1.14	**	(0.48)	1.14	**	(0.48)	1.15	*	(0.54)	1.16	***	(0.42)
Rate (period 6)	.52	**	(0.21)	.50	***	(0.19)	.52	**	(0.22)	.51	***	(0.20)
Rate (period 7)	.68	***	(0.26)	.69	***	(0.25)	.69	***	(0.27)	.69	***	(0.23)
Rate (period 8)	.50	**	(0.19)	.50	**	(0.21)	.50	**	(0.20)	.50	**	(0.21)
Rate (period 9)	.50	**	(0.21)	.49	***	(0.19)	.51	**	(0.21)	.51	*	(0.23)
Linear Shape	-.41		(0.88)	-.41		(0.67)	-.42		(0.85)	-.33		(0.64)
Quadratic Shape	-.31		(0.38)	-.31		(0.27)	-.30		(0.27)	-.29		(0.23)
Indegree	-.03		(0.09)	-.03		(0.08)	-.02		(0.07)	-.02		(0.07)
Outdegree	.02		(0.07)	.03		(0.07)	.03		(0.07)	.02		(0.07)
Total Alter (Peer Influence)	-.08		(0.29)	-.10		(0.23)	-.07		(0.18)	-.07		(0.20)
Total Alter X Alter Role Model	1.17		(2.52)	1.18		(1.78)	1.03		(1.55)	1.00		(1.49)
Black Race	.52		(0.75)	.55		(0.63)	.51		(0.58)	.49		(0.54)
Hispanic Race	1.19		(1.55)	1.16		(1.05)	1.16		(1.14)	1.10		(0.99)
Age	.04		(0.05)	.04		(0.04)	.03		(0.03)	.03		(0.03)
Offense Gravity Score	.02		(0.06)	.02		(0.06)	.01		(0.06)	.01		(0.06)
TABE Score	.004		(0.008)	.004		(0.007)	.004		(0.007)	.004		(0.006)
TCU Score	-.08		(0.16)	-.08		(0.15)	-.08		(0.14)	-.08		(0.14)
Time on Unit	.005		(0.009)	.005		(0.009)	.005		(0.008)	.006		(0.007)

Note: Standard errors in parentheses. †p < .10; \*p < .05; \*\*p < .01; \*\*\*p < .001 (two-tailed tests).

❖ What do the authors find?

# Motivating Example

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Rate (period 6)	12.79	***	(0.96)	12.73	***	(1.01)	14.45	***	(1.07)	13.07	***	(1.06)
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Rate (period 1)	.70	*	(0.34)	.68	**	(0.28)	.71	***	(0.25)	.71	***	(0.24)
Rate (period 2)	.74	**	(0.29)	.76	***	(0.29)	.76	**	(0.32)	.77	**	(0.30)
Rate (period 3)	.96	†	(0.51)	.97	**	(0.38)	.98	*	(0.44)	.98	**	(0.39)
Rate (period 4)	.63	*	(0.31)	.64	**	(0.26)	.65	***	(0.24)	.65	**	(0.25)
Rate (period 5)	1.14	**	(0.48)	1.14	**	(0.48)	1.15	*	(0.54)	1.16	***	(0.42)
Rate (period 6)	.52	**	(0.21)	.50	***	(0.19)	.52	**	(0.22)	.51	***	(0.20)
Rate (period 7)	.68	***	(0.26)	.69	***	(0.25)	.69	***	(0.27)	.69	***	(0.23)
Rate (period 8)	.50	**	(0.19)	.50	**	(0.21)	.50	**	(0.20)	.50	**	(0.21)
Rate (period 9)	.50	**	(0.21)	.49	***	(0.19)	.51	**	(0.21)	.51	*	(0.23)
Linear Shape	-.41		(0.88)	-.41		(0.67)	-.42		(0.85)	-.33		(0.64)
Quadratic Shape	-.31		(0.38)	-.31		(0.27)	-.30		(0.27)	-.29		(0.23)
Indegree	-.03		(0.09)	-.03		(0.08)	-.02		(0.07)	-.02		(0.07)
Outdegree	.02		(0.07)	.03		(0.07)	.03		(0.07)	.02		(0.07)
Total Alter (Peer Influence)	-.08		(0.29)	-.10		(0.23)	-.07		(0.18)	-.07		(0.20)
Total Alter X Alter Role Model	1.17		(2.52)	1.18		(1.78)	1.03		(1.55)	1.00		(1.49)
Black Race	.52		(0.75)	.55		(0.63)	.51		(0.58)	.49		(0.54)
Hispanic Race	1.19		(1.55)	1.16		(1.05)	1.16		(1.14)	1.10		(0.99)
Age	.04		(0.05)	.04		(0.04)	.03		(0.03)	.03		(0.03)
Offense Gravity Score	.02		(0.06)	.02		(0.06)	.01		(0.06)	.01		(0.06)
TABE Score	.004		(0.008)	.004		(0.007)	.004		(0.007)	.004		(0.006)
TCU Score	-.08		(0.16)	-.08		(0.15)	-.08		(0.14)	-.08		(0.14)
Time on Unit	.005		(0.009)	.005		(0.009)	.005		(0.008)	.006		(0.007)

Note: Standard errors in parentheses. †p < .10; \*p < .05; \*\*p < .01; \*\*\*p < .001 (two-tailed tests).

❖ How do they do it?

❖ Coevolution models!

*Statistical Analysis of Networks*

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# Coevolution of Networks and Behavior

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# Learning Goals

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- ❖ By the end of this lecture, you should be able to answer these questions:
  - ❖ What is the basic logic of the coevolution model?
  - ❖ Why use the coevolution model?
  - ❖ What are **network** and **behavior** configurations?



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# Introduction

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- ❖ Last week: How do networks change? (network dynamics)
- ❖ This week: a new question...
  - ❖ *How do networks **and** behavior coevolve?*

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# Interdependence

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- ❖ As we have seen, tie formation (i.e. network dynamics) can depend on behavior.
- ❖ Examples:
  - ❖ Homophily (Ego has a preference for being tied to alters with similar / same attribute values)
  - ❖ Receiver & Sender Effects (Ego has a preference for sending ties to those with a particular attribute)

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# Interdependence

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- ❖ However, *behavior* can depend on network properties.
- ❖ Examples:
  - ❖ Assimilation / Contagion (adopting attitudes of those around you)
  - ❖ Isolation (those with no friends may become depressed)

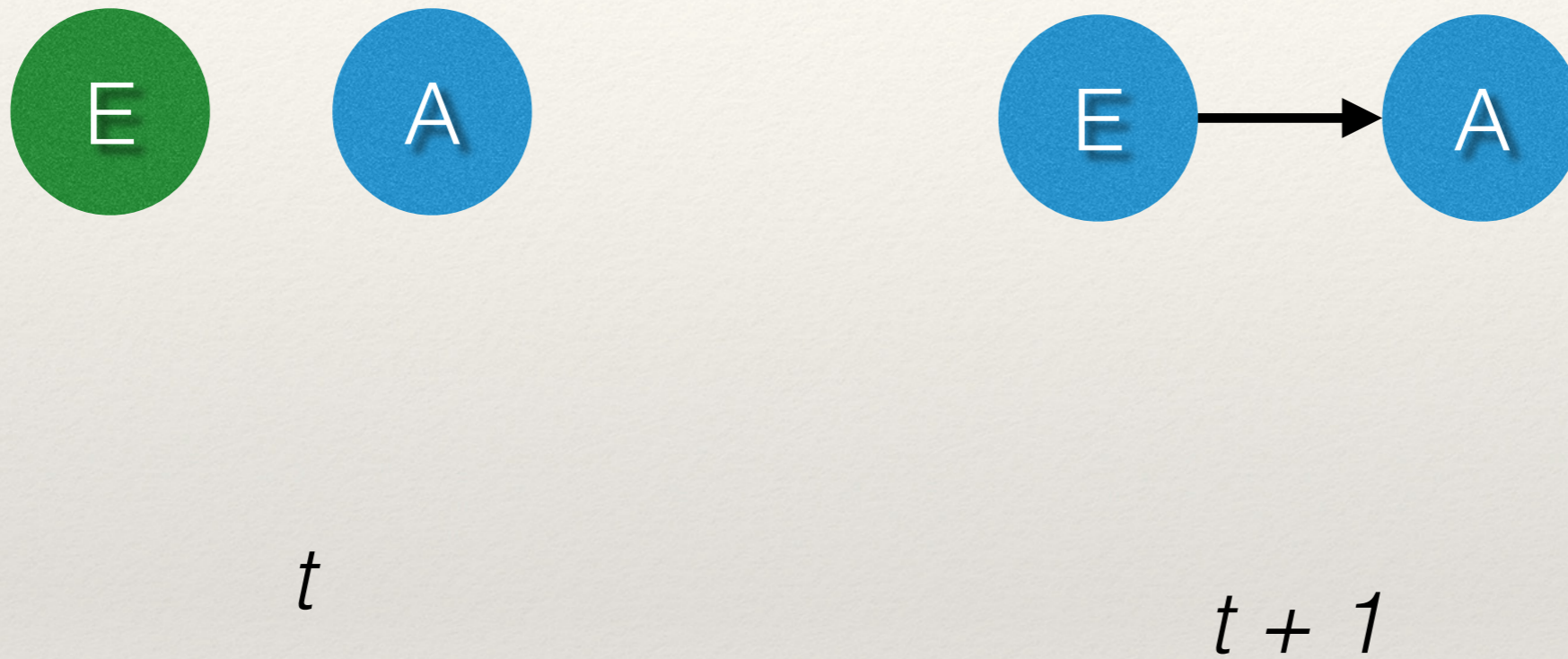
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# Separating Mechanisms

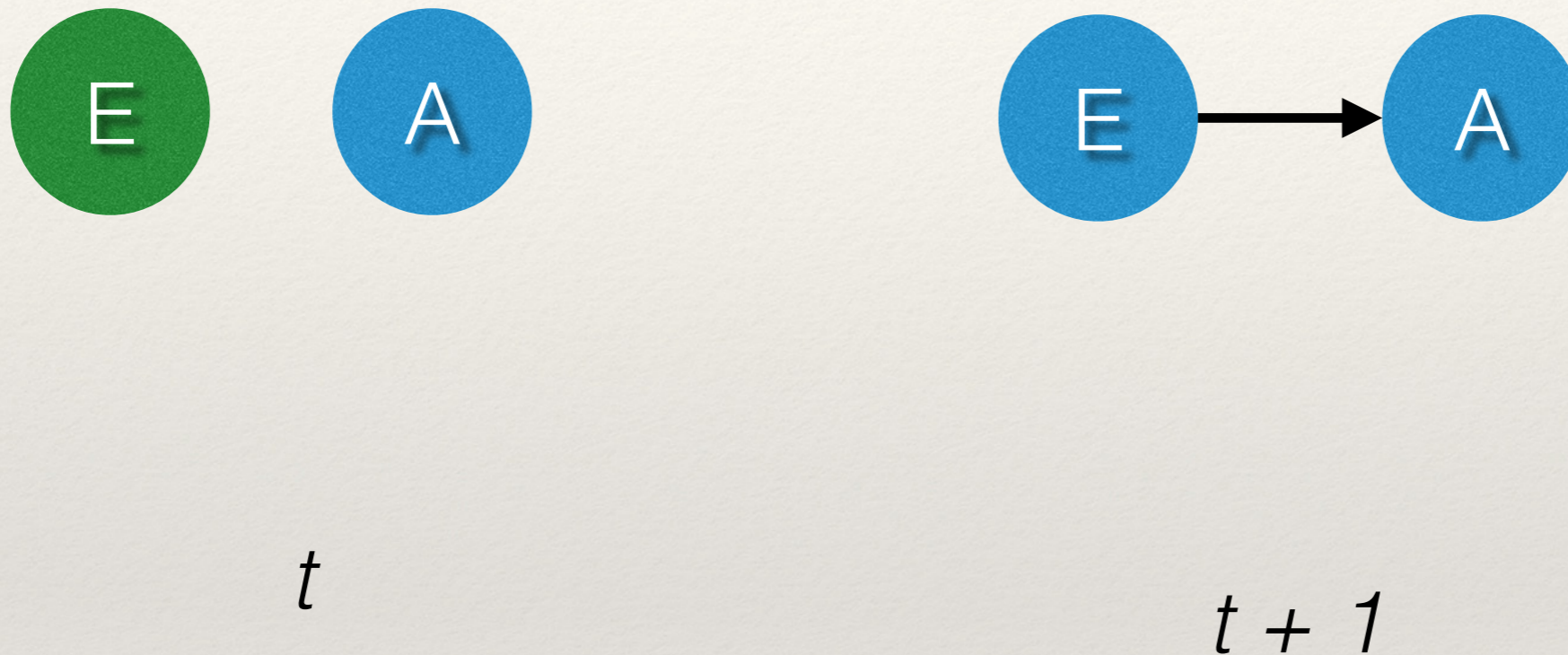
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- ❖ As a consequence, we are trying to separate the mechanisms that generate the networks we observe.
- ❖ Example:
  - ❖ Delinquent individuals **select** delinquent friends.
  - ❖ *Or*, individuals engage in delinquency if their friends do.
  - ❖ In the cross-section, we cannot determine which mechanism is correct (could be either or both).

Say we observe these two  
cross-sections

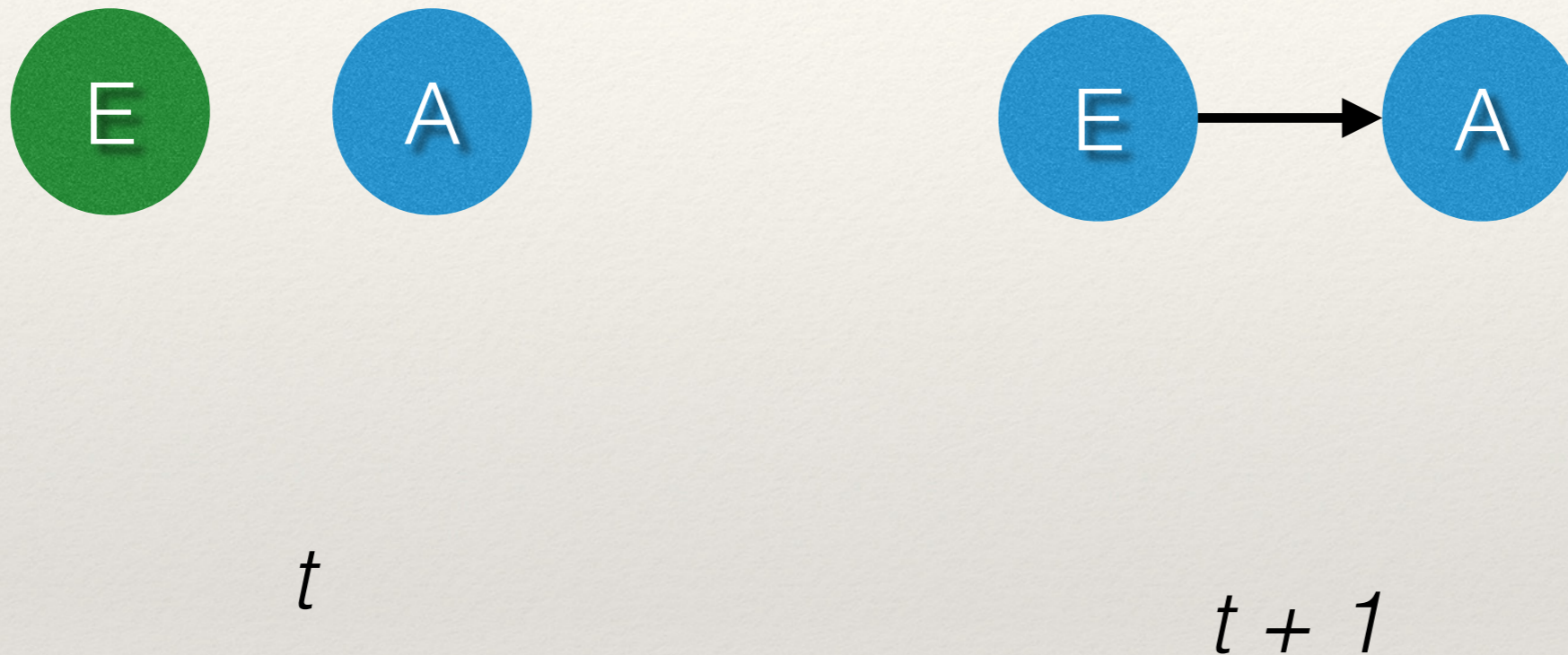


Say we observe these two  
cross-sections



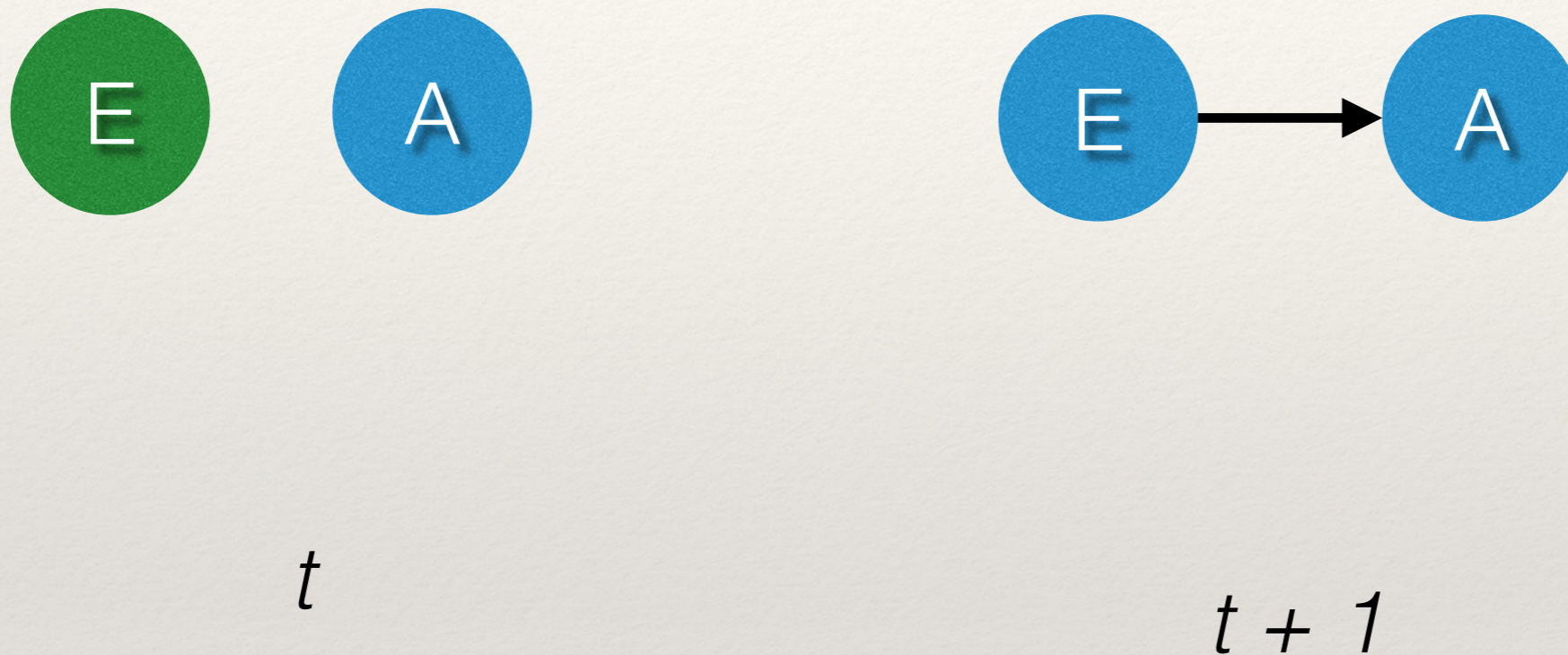
At time  $t$ , **ego** is a different  
“type” or attribute value than  
**alter** and is not connected to  
**alter**.

Say we observe these two  
cross-sections



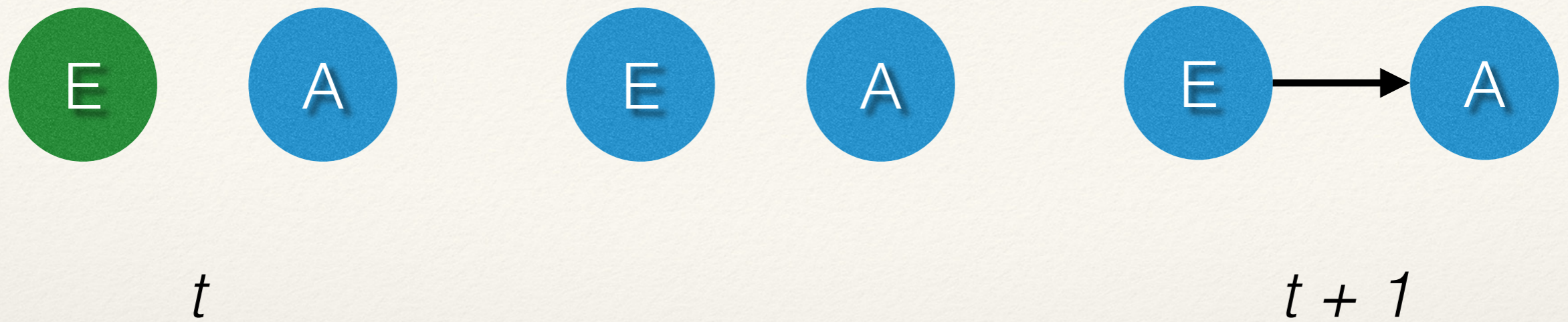
At time  $t + 1$ , **ego** is the same  
“type” or attribute value as **alter**  
and is connected to **alter**.

Say we observe these two  
cross-sections



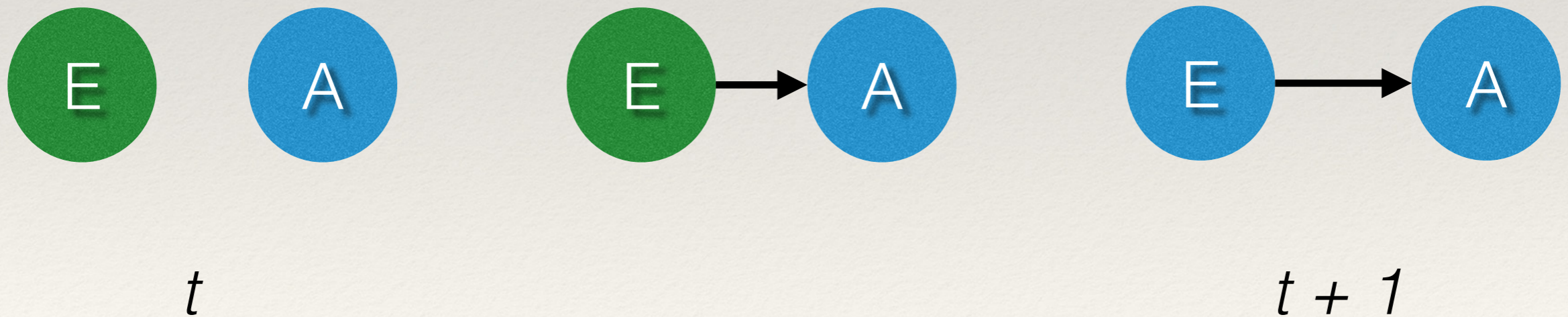
Let's think about the ways that this  
could have occurred (i.e. micro-steps).

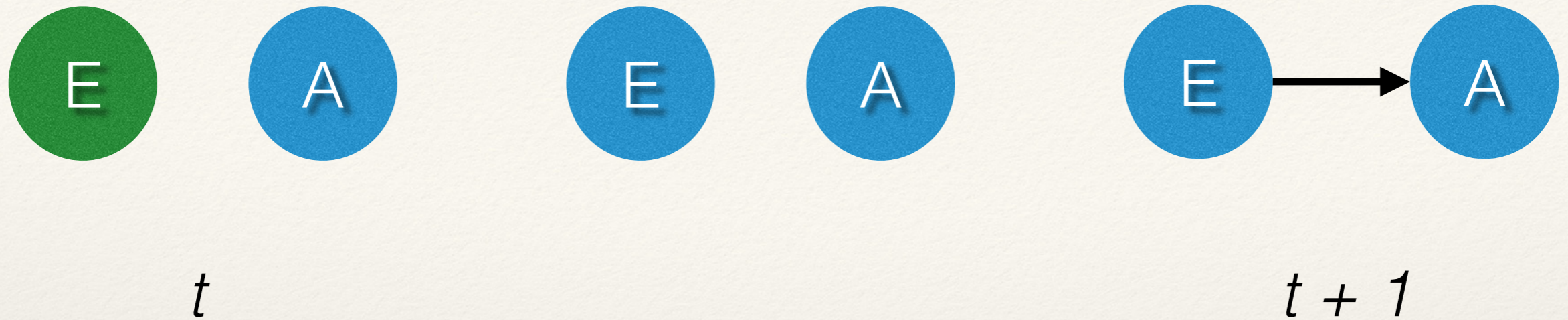




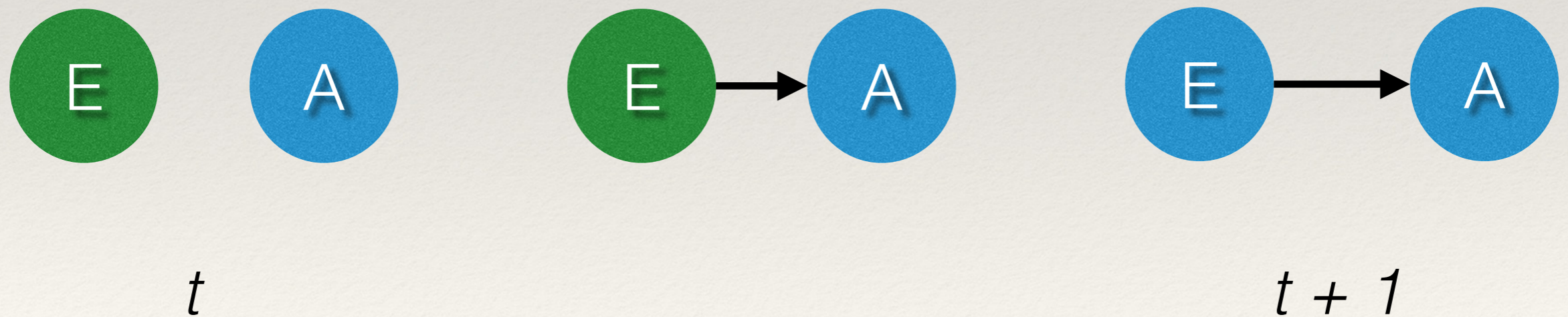
Ego changes his behavior, **then**  
befriends alter.

Ego befriends alter, **then** changes his behavior.





We would like a model that shows the coevolution of both the network and behavior.



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# Separating Mechanisms

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- ❖ The basic problem is trying to determine whether the observed network is a consequence of:
  - ❖ The network leading to behavioral alignment
  - ❖ Actors' behavior leading to network alignment
    - ❖ Coevolution models aim to construct a model that can tease these apart.

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# Stochastic Actor-Based Models

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- ❖ We can extend the SABM logic to a behavioral domain.
- ❖ Now, actors control:
  - ❖ Their ties
  - ❖ Their behavior

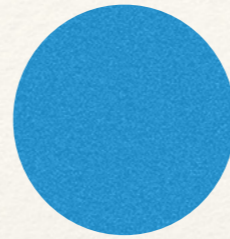
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# Stochastic Actor-Based Models

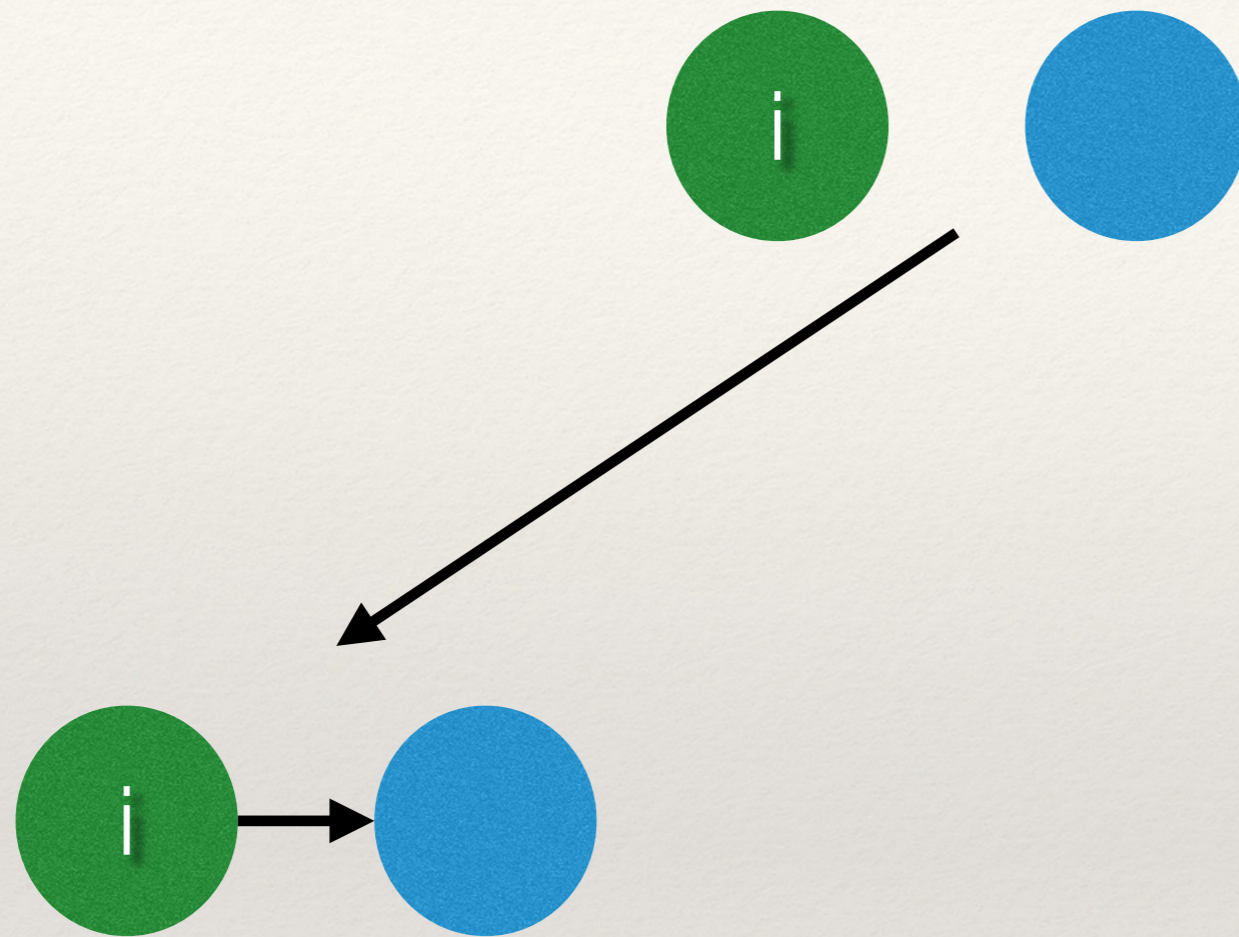
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- ❖ We simply extend the functions to include behavior:
  - ❖ **Rate** functions for the network *and* for behavior.
    - ❖ How frequently are individuals changing ties?  
Their behavior?
  - ❖ **Objective** functions for the network and behavior.
    - ❖ What are actors' preferences for their ties? Their behavior?

What can *i* do?



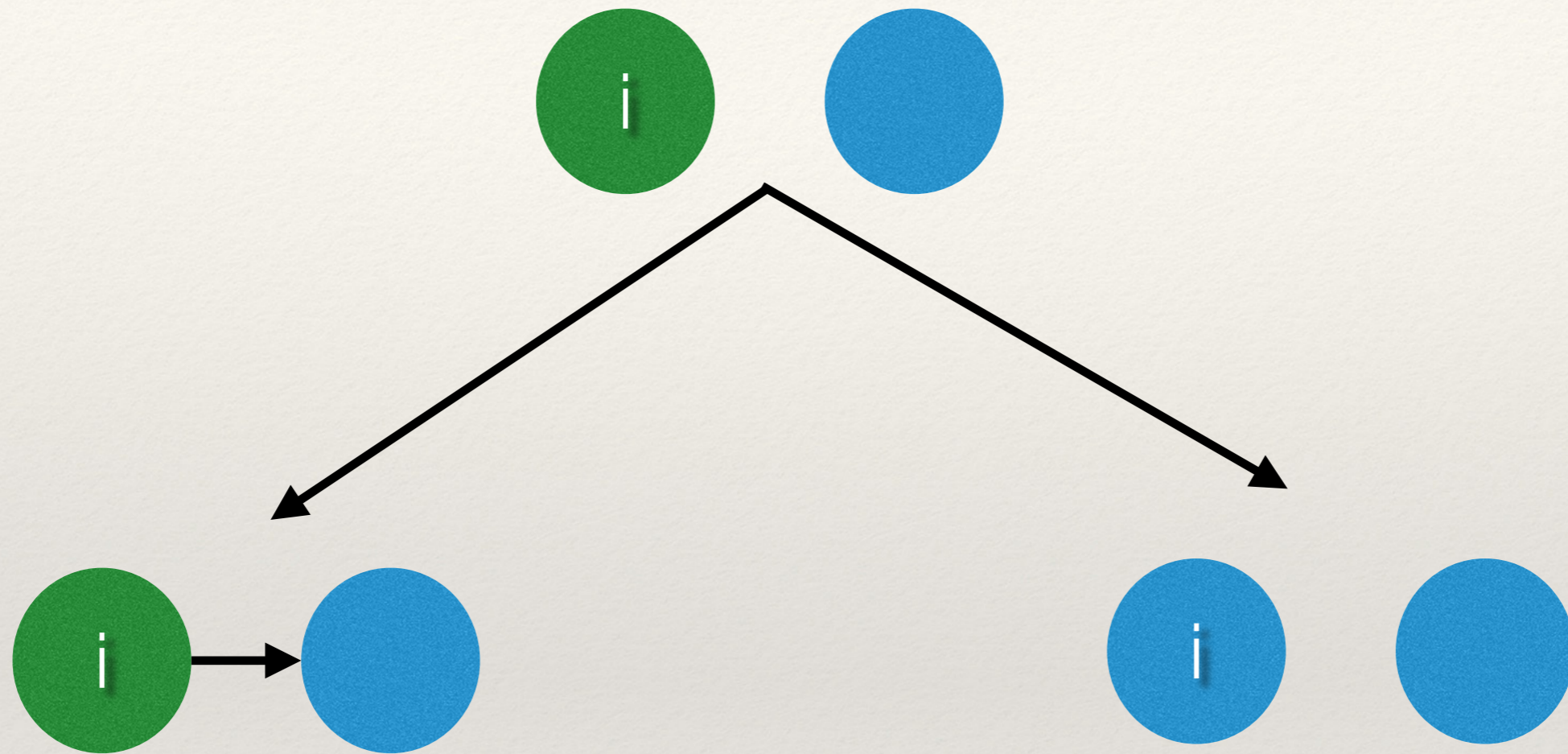
What can  $i$  do?



Change network  
(*network objective function*)



What can  $i$  do?



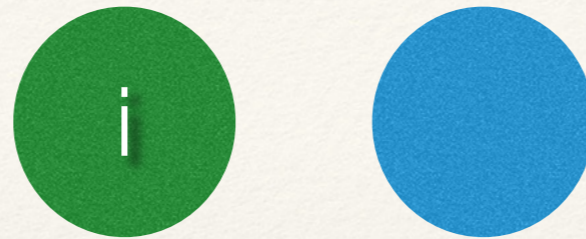
Change network

*(network objective function)*

Change behavior

*(behavior objective function)*

What can  $i$  do?



Not making any changes  
(*behavior and network rate functions*)

is still an option as well

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# Objective Function

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- ❖ As before, we want to specify the configurations.
- ❖ But, what is different is that in addition to **network configurations**, we are going to specify **behavioral configurations**.

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# Basic Effects

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# Basic Effects

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$t$

$t+1$

Effect  
(RSiena term)

Preference

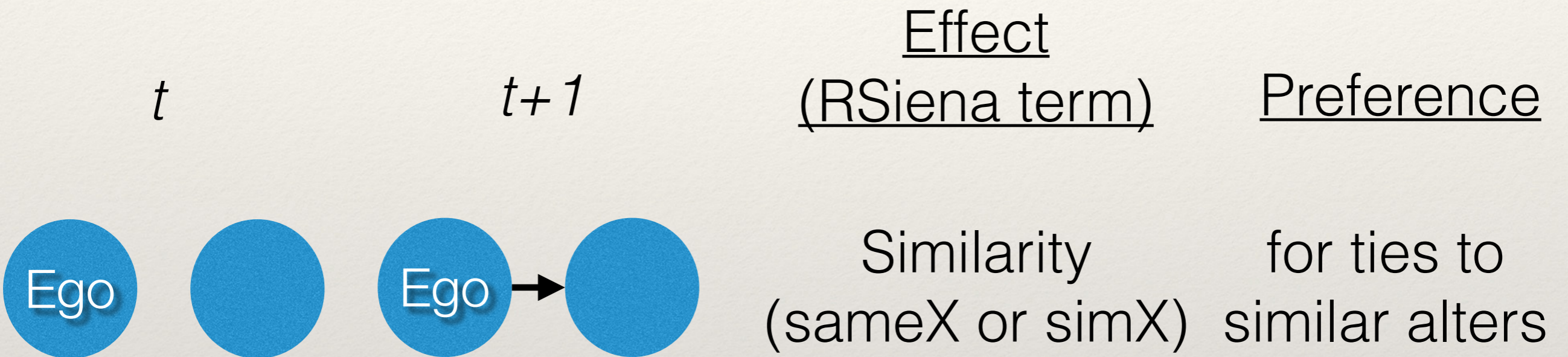
for ties to  
similar alters



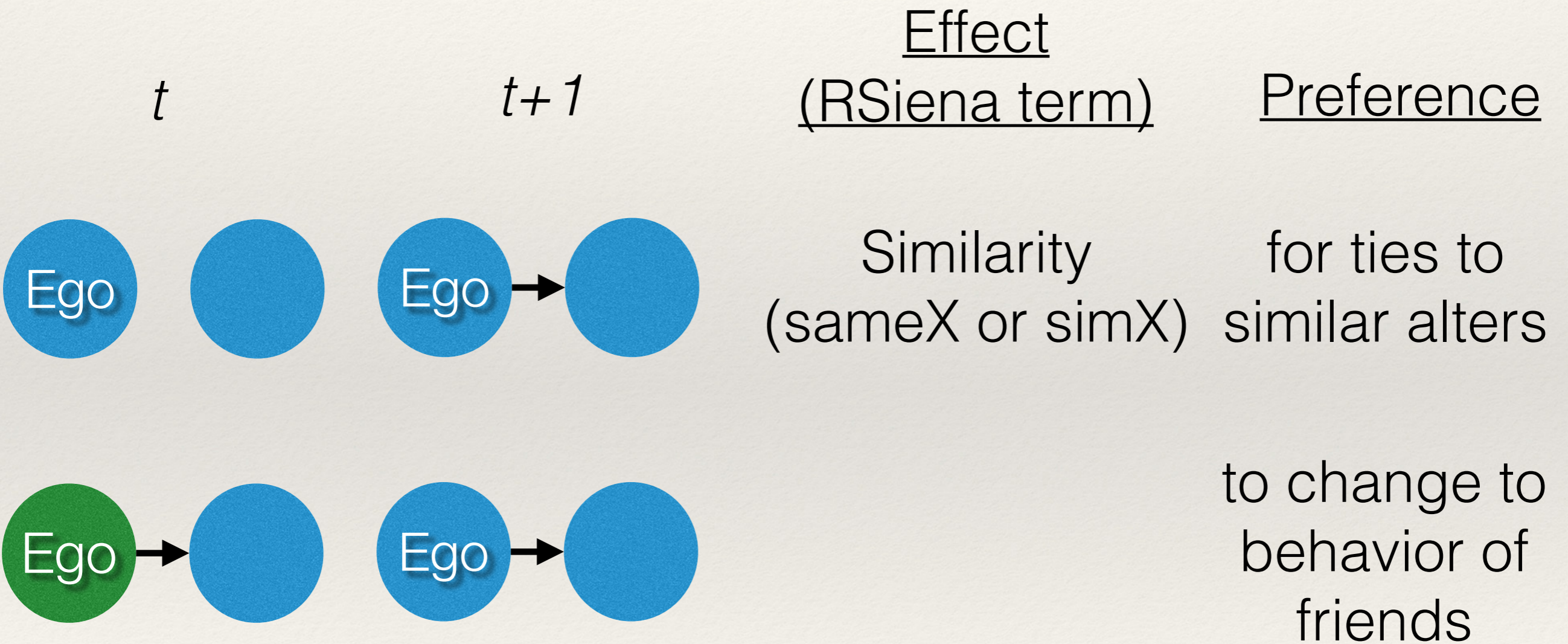
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# Basic Effects

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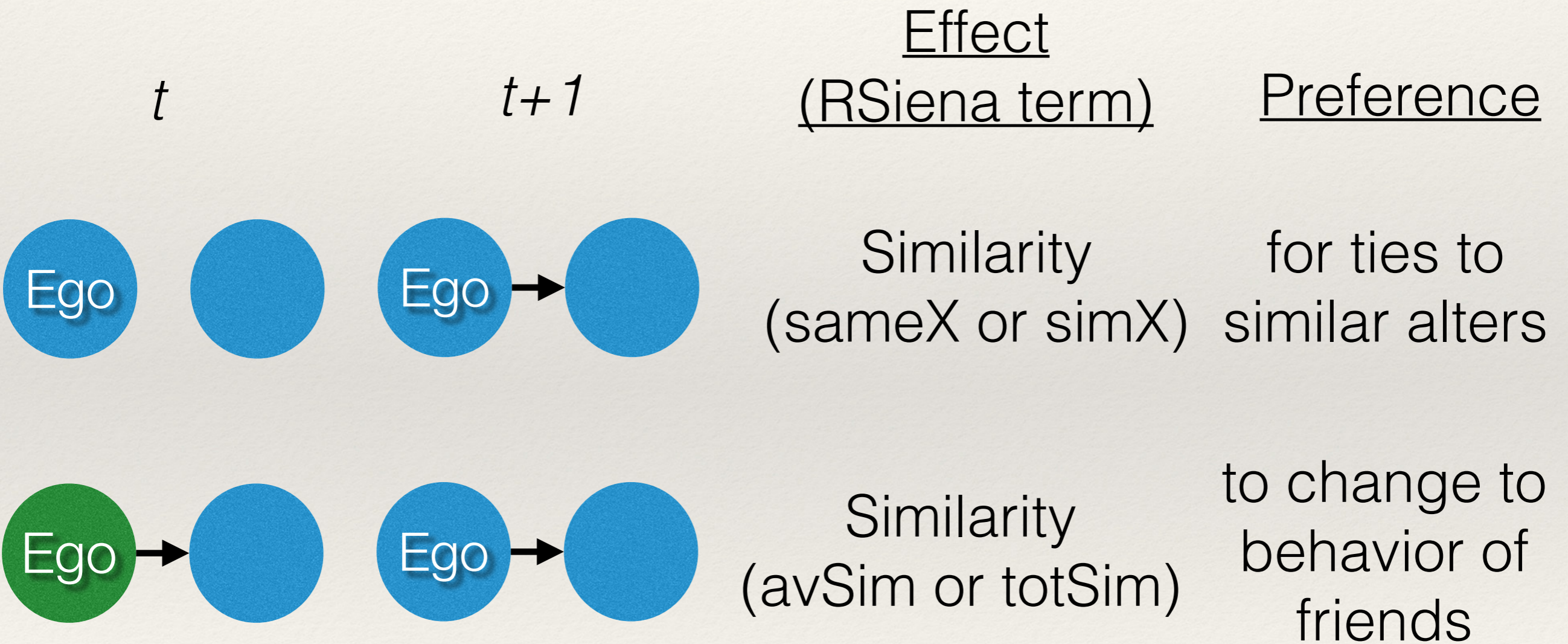
# Basic Effects



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# Basic Effects

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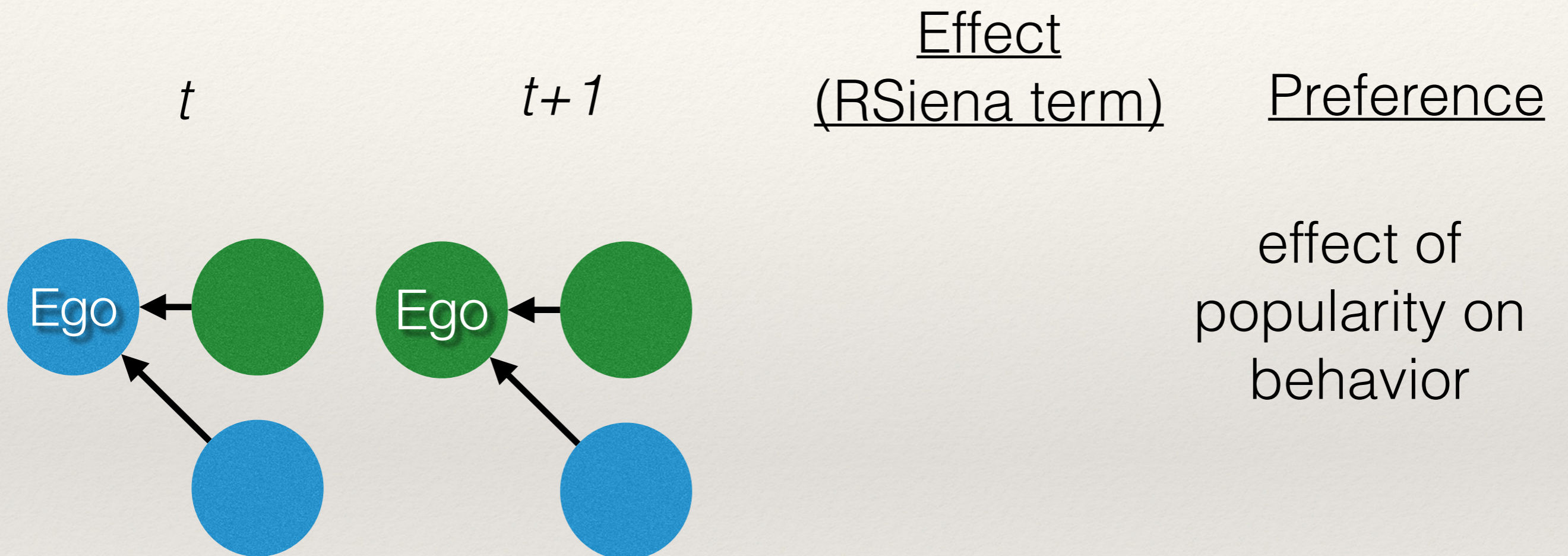


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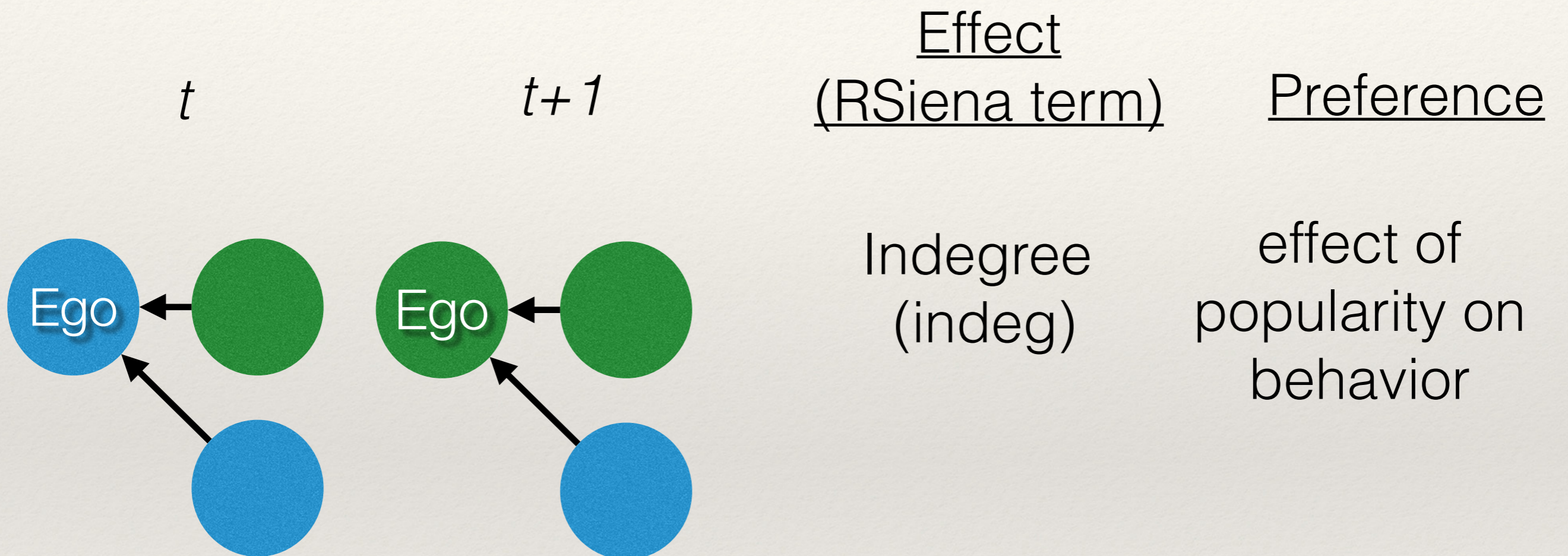
# Interactions w/ Covariates

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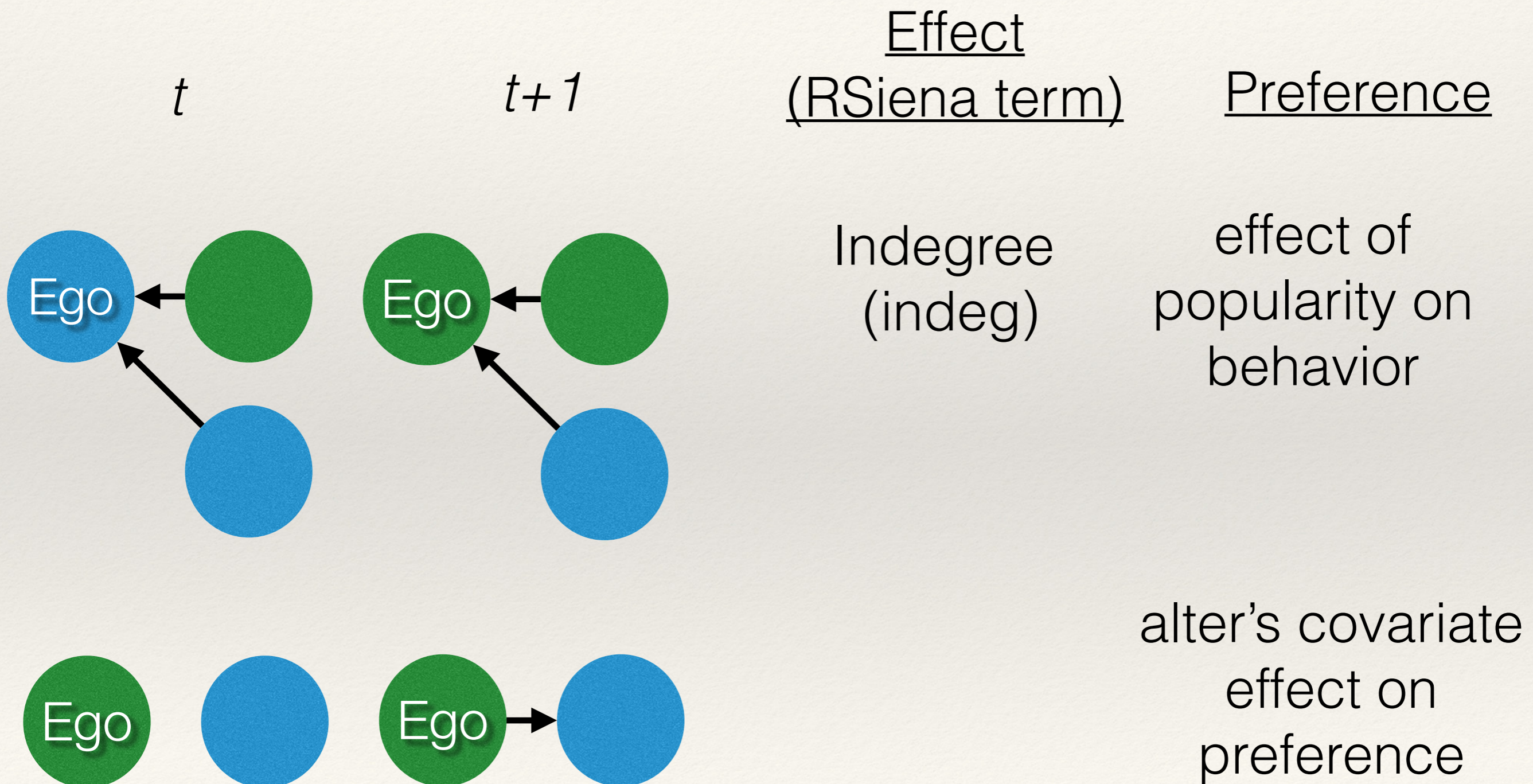
# Interactions w/ Covariates



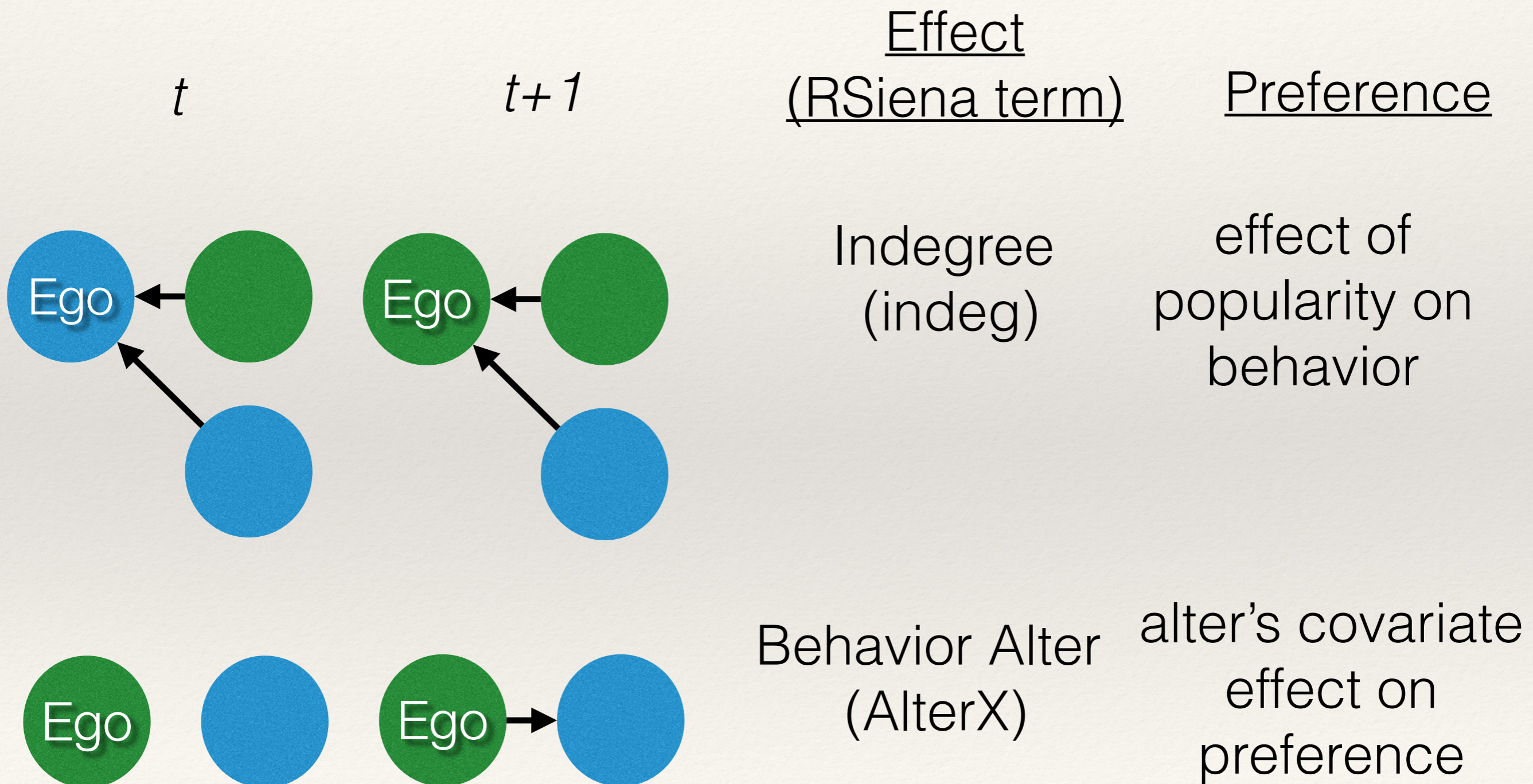
# Interactions w/ Covariates



# Interactions w/ Covariates



# Interactions w/ Covariates



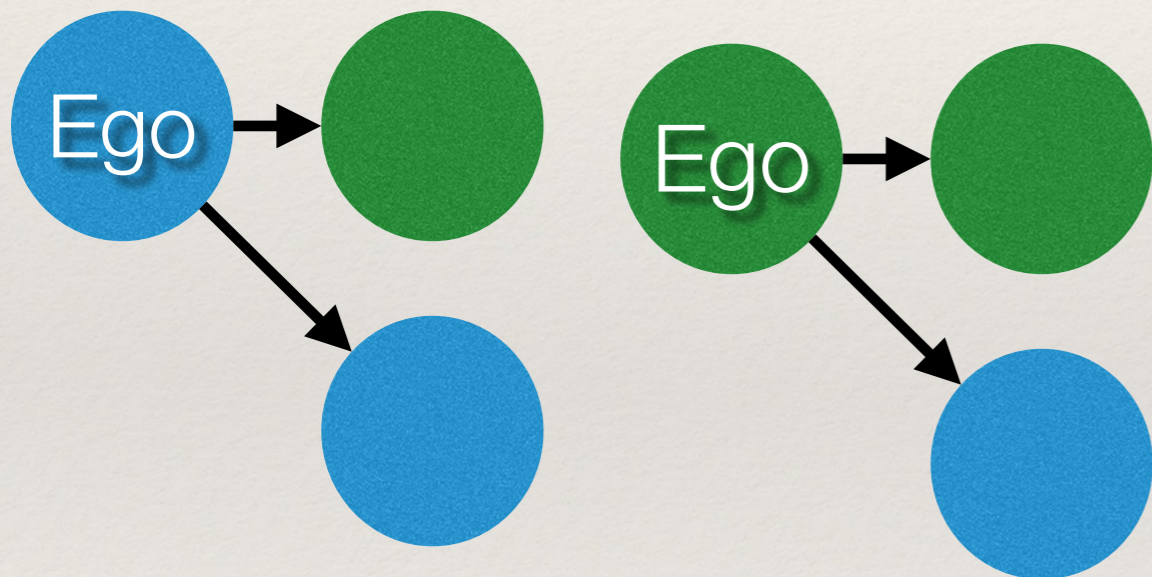
# Interactions w/ Covariates

$t$

$t+1$

Effect  
(RSiena term)

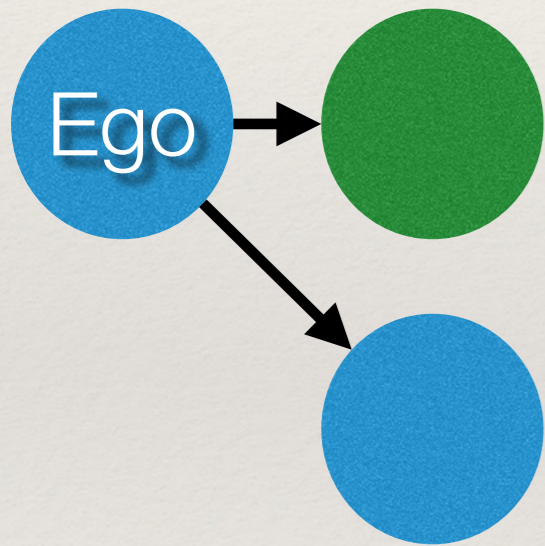
Preference



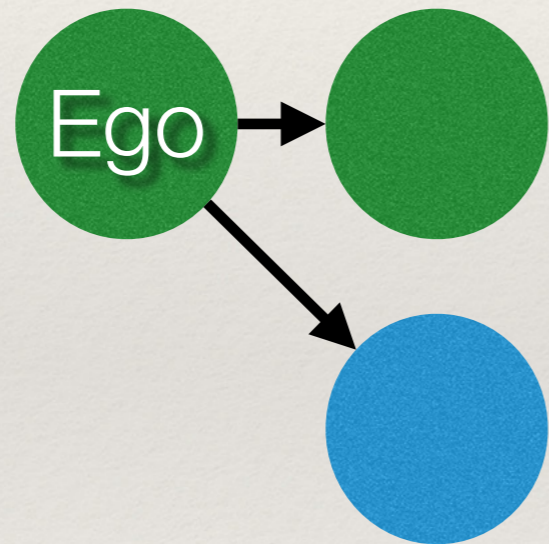
effect of activity  
on behavior

# Interactions w/ Covariates

$t$



$t+1$



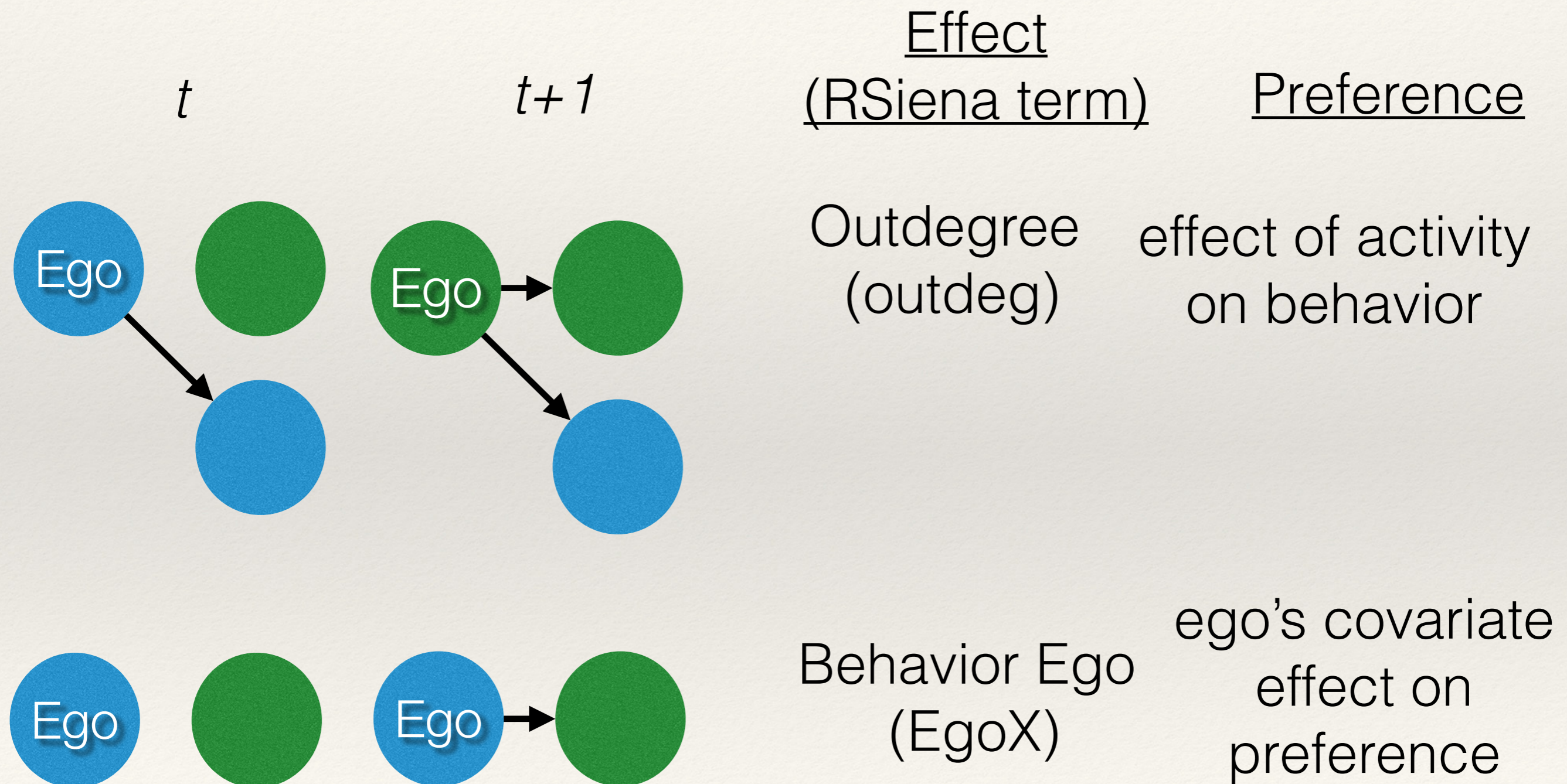
Effect  
(RSiena term)

Outdegree  
(outdeg)

Preference

effect of activity  
on behavior

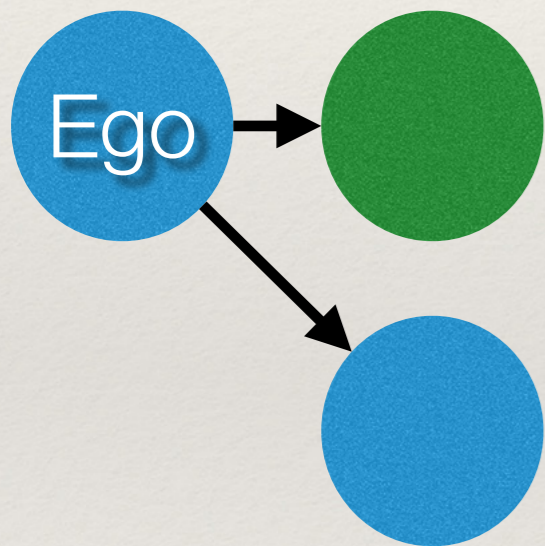
# Interactions w/ Covariates



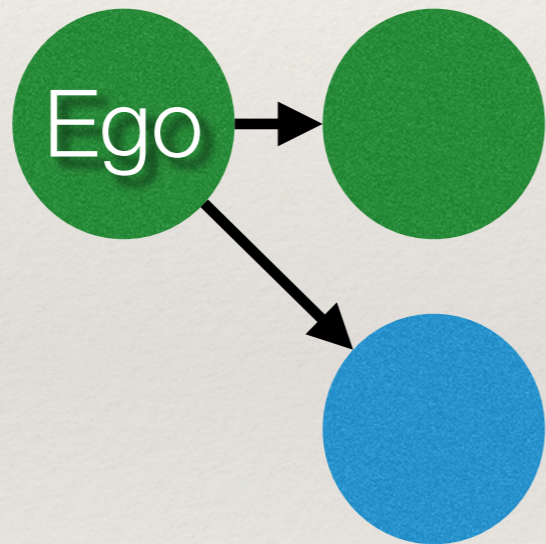


# Interactions w/ Covariates

$t$



$t+1$



Effect  
(RSiena term)

Outdegree  
(outdeg)

Preference

effect of activity  
on behavior

Note the difference from EgoX

# Motivating Example

**Table 1**  
Stochastic Actor-Oriented Models of Social Ties in a Prison Therapeutic Community.

Network Selection Function	M1			M2			M3			M4		
	b		(se)	b		(se)	b		(se)	b		(se)
Rate (period 1)	16.95	***	(1.38)	16.06	***	(1.28)	17.26	***	(1.19)	14.49	***	(1.07)
Rate (period 2)	10.46	***	(0.76)	10.26	***	(0.86)	10.58	***	(0.77)	9.63	***	(0.74)
Rate (period 3)	9.28	***	(0.81)	9.34	***	(0.91)	9.38	***	(0.82)	8.56	***	(0.74)
Rate (period 4)	13.02	***	(1.12)	13.59	***	(1.41)	14.37	***	(1.18)	12.99	***	(1.13)
Rate (period 5)	15.60	***	(1.15)	15.89	***	(1.37)	16.65	***	(1.18)	14.64	***	(1.04)
Rate (period 6)	12.79	***	(0.96)	12.73	***	(1.01)	14.45	***	(1.07)	13.07	***	(1.06)
Rate (period 7)	12.88	***	(0.90)	13.18	***	(1.16)	14.11	***	(1.12)	13.12	***	(1.03)
Rate (period 8)	14.89	***	(1.09)	15.38	***	(1.24)	16.65	***	(1.30)	15.12	***	(1.17)
Rate (period 9)	12.66	***	(1.14)	12.59	***	(1.09)	13.70	***	(1.10)	12.66	***	(1.07)
Outdegree (density)	-.80	***	(0.03)	-1.43	***	(0.03)	-1.15	***	(0.05)	-1.67	***	(0.05)
Reciprocity				1.67	***	(0.09)				1.58	***	(0.09)
Transitive Triplets				.25	***	(0.02)				.29	***	(0.02)
Transitive Reciprocal Triplets				-.31	***	(0.05)				-.31	***	(0.05)
Same Race							.67	***	(0.05)	.53	***	(0.05)
Alter Age							-.009	***	(0.002)	-.007	***	(0.002)
Ego Age							.009	**	(0.004)	.009	***	(0.003)
Age Similarity							.87	***	(0.12)	.75	***	(0.11)
Alter Offense Gravity Score							.01		(0.01)	.01	†	(0.01)
Ego Offense Gravity Score							.03	*	(0.01)	.02	*	(0.01)
Offense Gravity Score Similarity							.14		(0.16)	.06		(0.15)
Alter TABE Score							.002	*	(0.001)	.001		(0.001)
Ego TABE Score							-.001		(0.001)	-.001		(0.001)
TABE Similarity							.24	***	(0.09)	.22	***	(0.09)
Alter TCU Score							.03		(0.02)	.01		(0.02)
Ego TCU Score							.08	*	(0.03)	.04		(0.03)
TCU Score similarity							.25	†	(0.14)	.16		(0.13)
Alter Time on Unit							-.001		(0.001)	-.005	***	(0.001)
Ego Time on Unit							-.008	***	(0.001)	-.010	***	(0.001)
Time on Unit Similarity							1.83	***	(0.11)	1.19	***	(0.12)
Alter Treatment Engagement	-.01		(0.03)	-.07	**	(0.03)	.07	*	(0.03)	-.001		(0.03)
Ego Treatment Engagement	.15	***	(0.03)	.09	***	(0.03)	.24	***	(0.04)	.16	***	(0.03)
Trtmt. Engagement Similarity	.46	***	(0.16)	.32	*	(0.14)	.22		(0.16)	.07		(0.16)
<i>Engagement Function</i>												
Rate (period 1)	.70	*	(0.34)	.68	**	(0.28)	.71	***	(0.25)	.71	***	(0.24)
Rate (period 2)	.74	**	(0.29)	.76	***	(0.29)	.76	**	(0.32)	.77	**	(0.30)
Rate (period 3)	.96	†	(0.51)	.97	**	(0.38)	.98	*	(0.44)	.98	**	(0.39)
Rate (period 4)	.63	*	(0.31)	.64	**	(0.26)	.65	***	(0.24)	.65	**	(0.25)
Rate (period 5)	1.14	**	(0.48)	1.14	**	(0.48)	1.15	*	(0.54)	1.16	***	(0.42)
Rate (period 6)	.52	**	(0.21)	.50	***	(0.19)	.52	**	(0.22)	.51	***	(0.20)
Rate (period 7)	.68	***	(0.26)	.69	***	(0.25)	.69	***	(0.27)	.69	***	(0.23)
Rate (period 8)	.50	**	(0.19)	.50	**	(0.21)	.50	**	(0.20)	.50	**	(0.21)
Rate (period 9)	.50	**	(0.21)	.49	***	(0.19)	.51	**	(0.21)	.51	*	(0.23)
Linear Shape	-.41		(0.88)	-.41		(0.67)	-.42		(0.85)	-.33		(0.64)
Quadratic Shape	-.31		(0.38)	-.31		(0.27)	-.30		(0.27)	-.29		(0.23)
Indegree	-.03		(0.09)	-.03		(0.08)	-.02		(0.07)	-.02		(0.07)
Outdegree	.02		(0.07)	.03		(0.07)	.03		(0.07)	.02		(0.07)
Total Alter (Peer Influence)	-.08		(0.29)	-.10		(0.23)	-.07		(0.18)	-.07		(0.20)
Total Alter X Alter Role Model	1.17		(2.52)	1.18		(1.78)	1.03		(1.55)	1.00		(1.49)
Black Race	.52		(0.75)	.55		(0.63)	.51		(0.58)	.49		(0.54)
Hispanic Race	1.19		(1.55)	1.16		(1.05)	1.16		(1.14)	1.10		(0.99)
Age	.04		(0.05)	.04		(0.04)	.03		(0.03)	.03		(0.03)
Offense Gravity Score	.02		(0.06)	.02		(0.06)	.01		(0.06)	.01		(0.06)
TABE Score	.004		(0.008)	.004		(0.007)	.004		(0.007)	.004		(0.006)
TCU Score	-.08		(0.16)	-.08		(0.15)	-.08		(0.14)	-.08		(0.14)
Time on Unit	.005		(0.009)	.005		(0.009)	.005		(0.008)	.006		(0.007)

Note: Standard errors in parentheses. †p < .10; \*p < .05; \*\*p < .01; \*\*\*p < .001 (two-tailed tests).

❖ What do the authors find?

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# Motivating Example

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## ❖ Peer influence?

Total Alter (Peer Influence)	-.07		(0.20)
Total Alter X Alter Role Model	1.00		(1.49)

## ❖ Selection?

Alter Treatment Engagement	-.001		(0.03)
Ego Treatment Engagement	.16	***	(0.03)
Trtmt. Engagement Similarity	.07		(0.16)

## ❖ Cross-dimensional selection?

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# Learning Goals

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- ❖ By the end of this lecture, you should be able to answer these questions:
  - ❖ What is the basic logic of the coevolution model?
  - ❖ Why use the coevolution model?
  - ❖ What are **network** and **behavior** configurations?

Questions?