

Opportunity and Impact

- Much focus is on financial incentives (lowering the price)
 - Going away (e.g., CSI incentives fully used up in San Diego county)
 - Electricity prices relatively low, particularly for low-use (tier 1) consumers
 - Financial incentives are costly
- Behavior motivated by numerous factors
 - Crucial to consider *financial, social, and psychological* incentives
 - Social: peer effects, group effects
 - Psychological: “control” (framed as energy independent)
- **Best Case:** predict effects of an *arbitrary panel* of incentive mechanisms, and choose optimal, cost efficient combinations
 - **Computational predictive platform:** *leverage data from past adoption decisions, surveys, and behavioral experiments*
 - **Computational optimization:** *choose best policy without having to try out all the different alternatives in the field*
 - **Use the right incentives, at the right time, in the right place, under tight budget constraints**

Outline

- Background: agent-based modeling
- The “Agent” model: a machine learning approach
- Agent-Based model, social influence, and adoption dynamics
- Optimal stimulation of PV adoption: computational dynamic optimization
- Behavioral experiments and surveys
- Past adoption patterns in San Diego county

Agent-Based Modeling

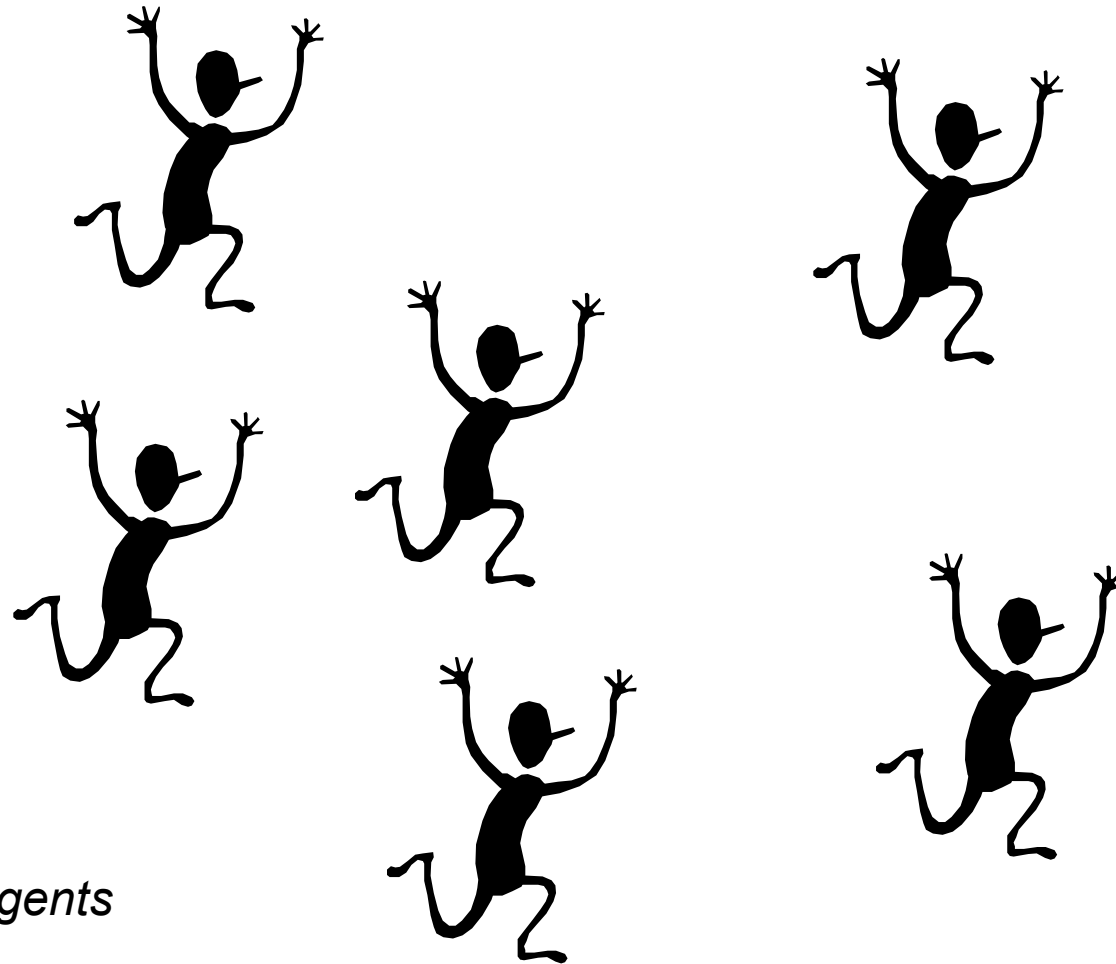
What is Agent-Based Modeling?

What is Agent-Based Modeling?

- Start with an agent:

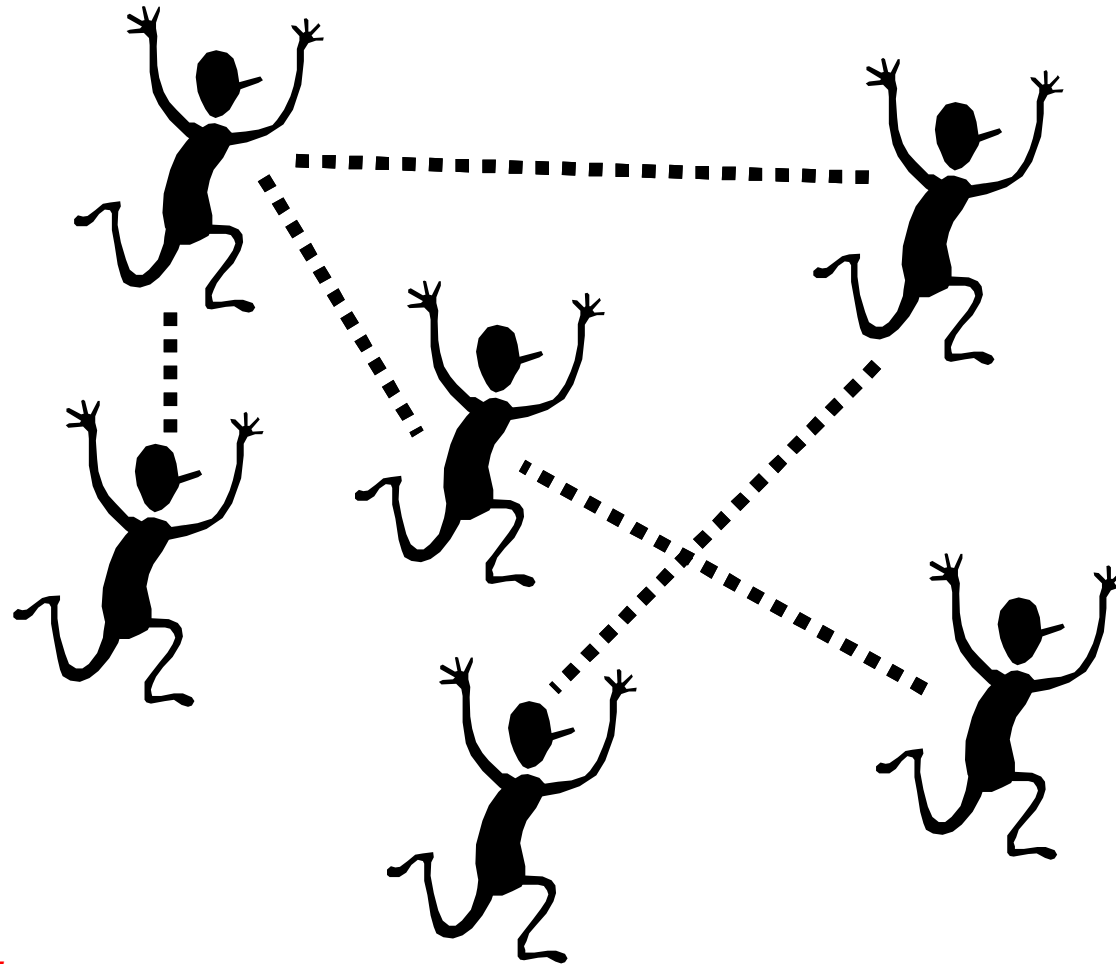


What is Agent-Based Modeling?



Instantiate many agents

What is Agent-Based Modeling?

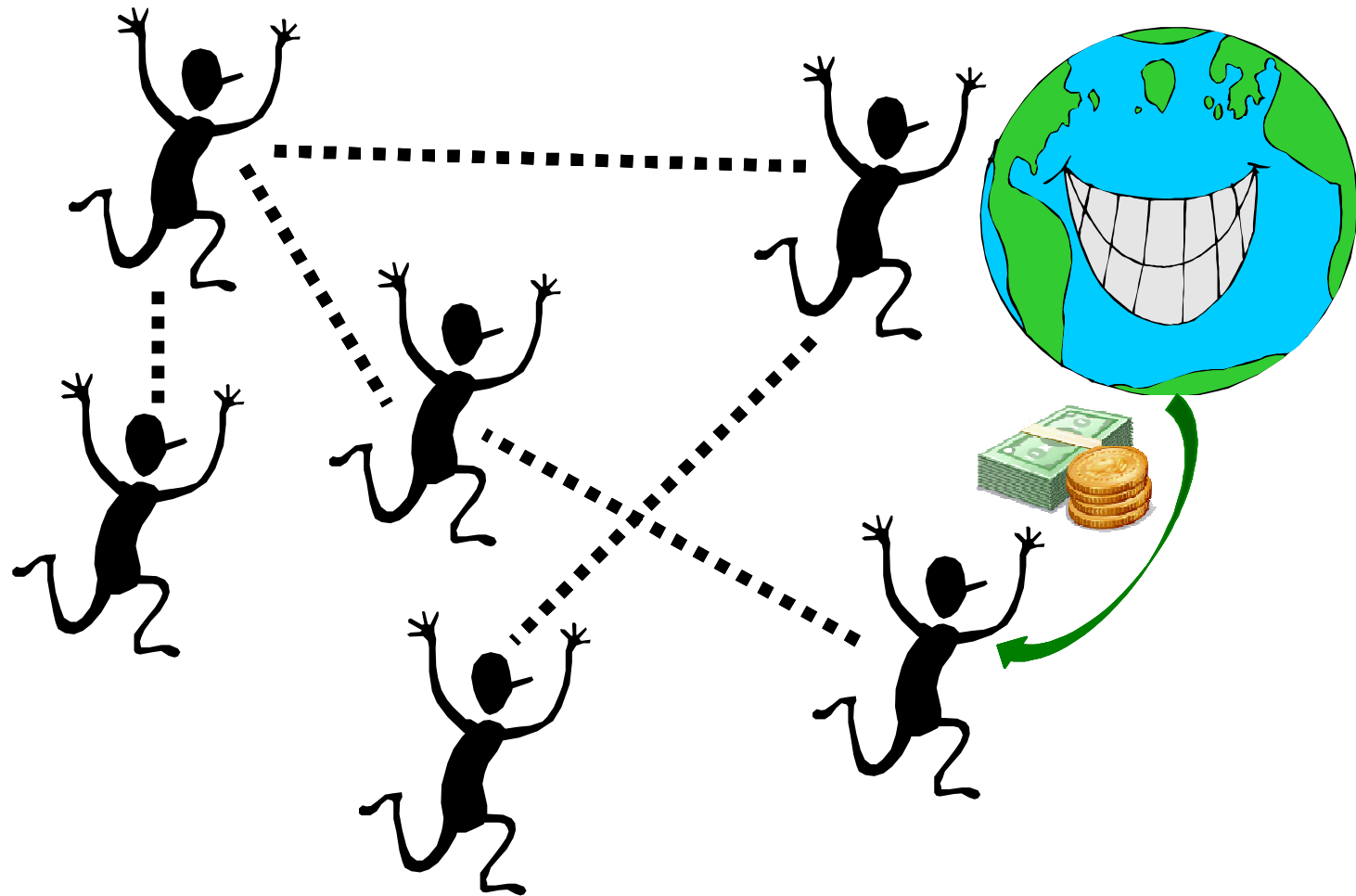


Agents interact

with each other

*Commonly, through a
contact network (which
may be changing)*

What is Agent-Based Modeling?



Agents interact

With the environment

Our approach: *predictive* agent-based modeling

- Agent behavior: calibrated from data
- Agent interactions: social influence
- *Evaluation*: predict data not used for calibration (“test data”)

The Agent Model

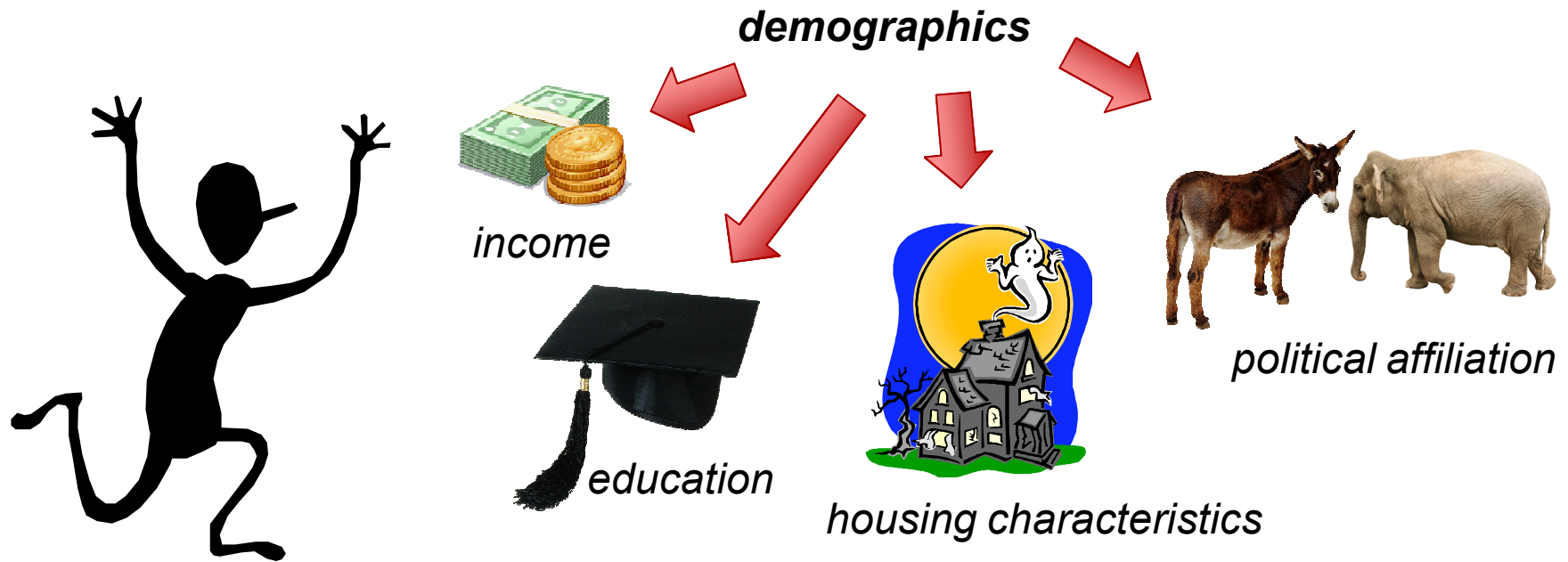
agent = home owner *who has not yet adopted PV at time t*

observe decision “context”:



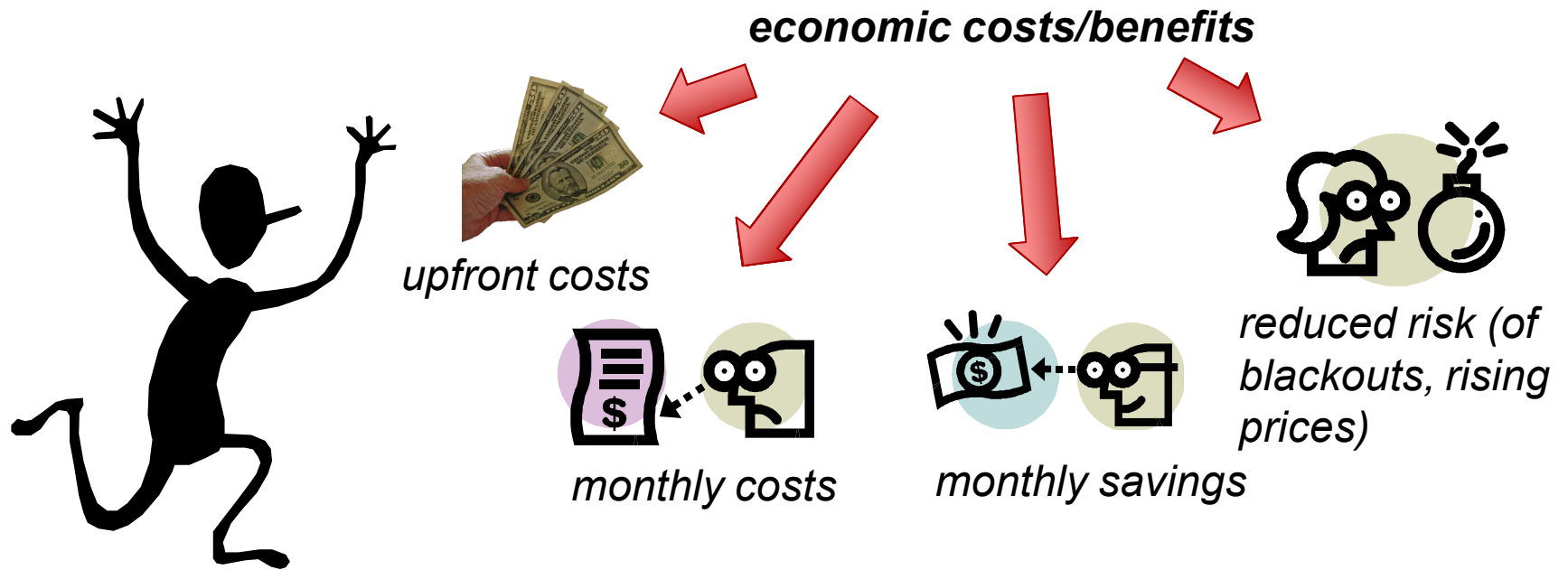
agent = home owner *who has not yet adopted PV at time t*

observe decision "context":



agent = home owner *who has not yet adopted PV at time t*

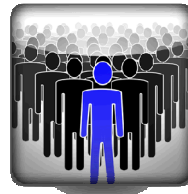
observe decision "context":



agent = home owner *who has not yet adopted PV at time t*

observe decision “context”:

social context (influence)



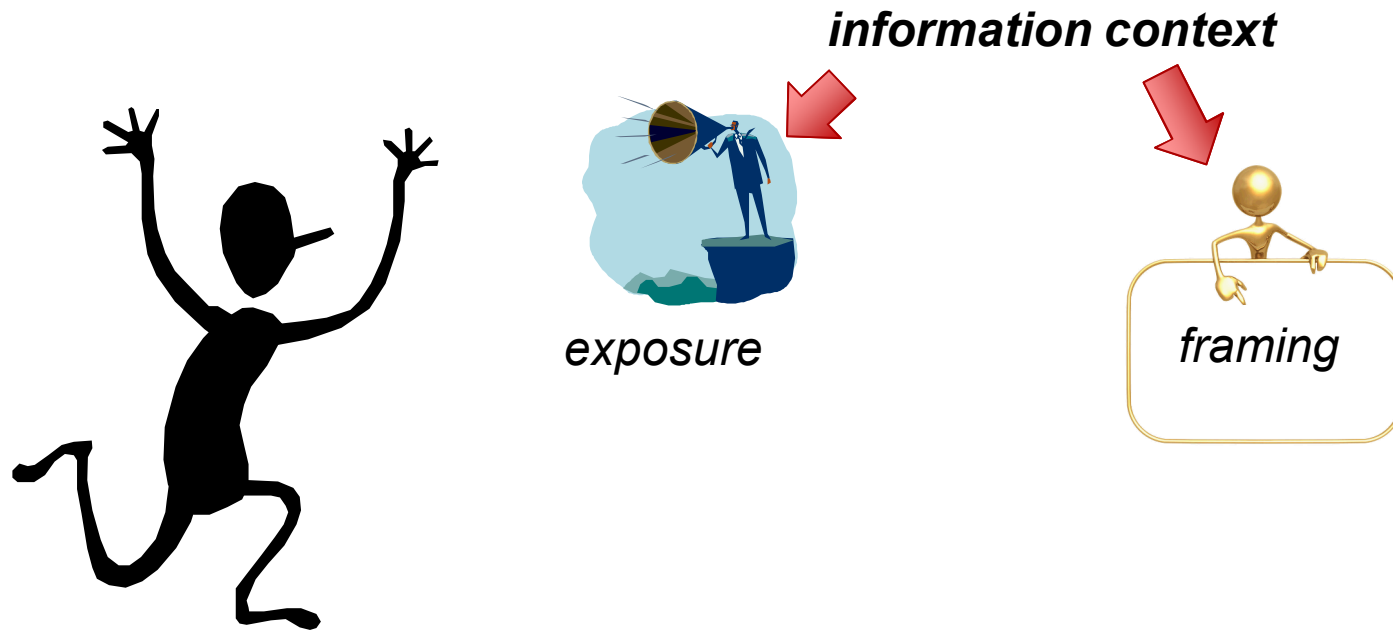
number of other adopters (friends, neighbors)



attitudes of friends/neighbors towards PV

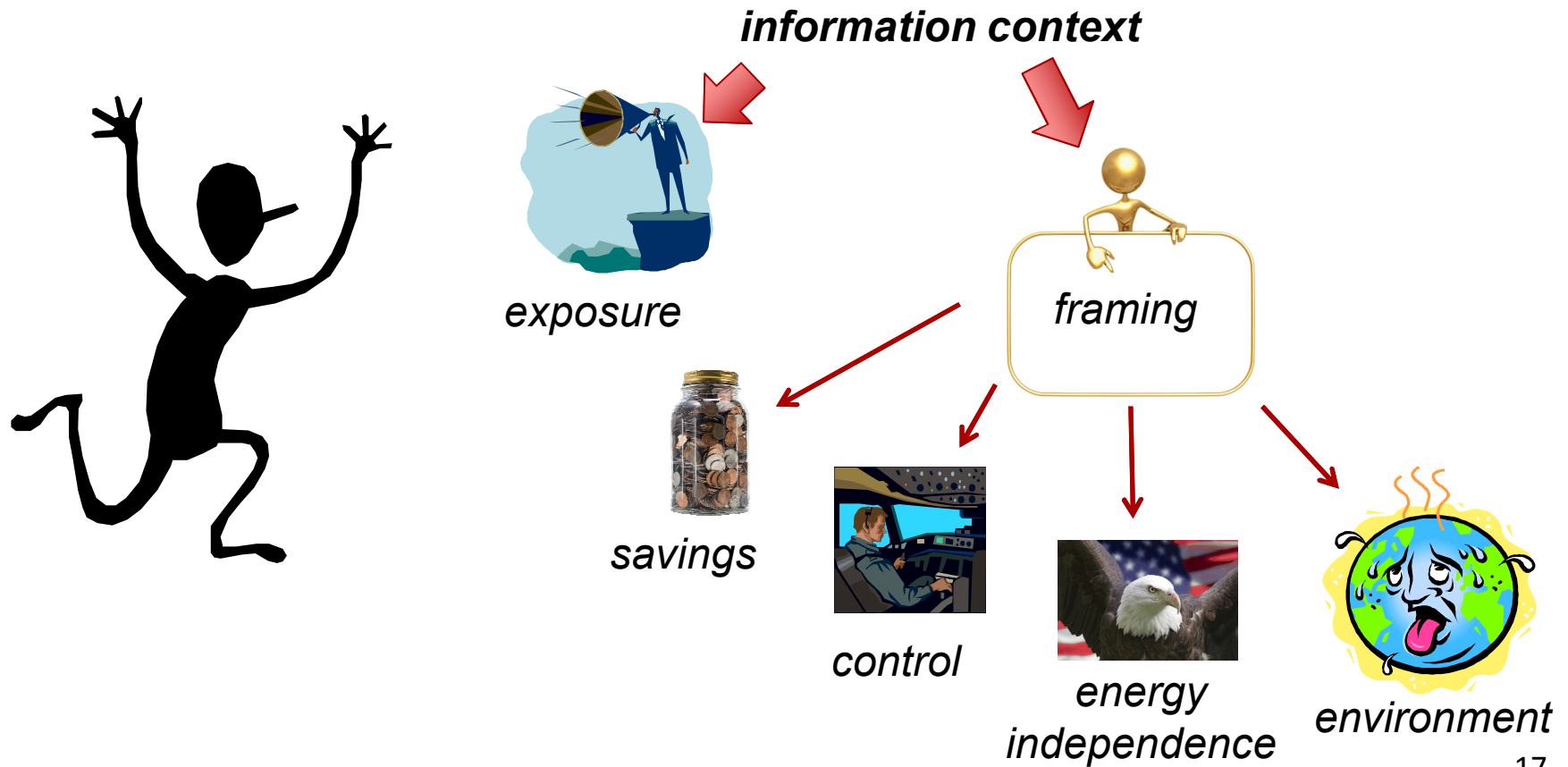
agent = home owner *who has not yet adopted PV at time t*

observe decision “context”:



agent = home owner *who has not yet adopted PV at time t*

observe decision "context":



agent = home owner *who has not yet adopted PV at time t*

predict decision (adopt or not)



agent = home owner *who has not yet adopted PV at time t*

predict decision (adopt or not)



demographics

economic costs/benefits

social context

information context

agent = home owner *who has not yet adopted PV at time t*

predict decision (adopt or not)



demographics

economic costs/benefits

social context

information context

Adopt PV?

Data Sources

demographics

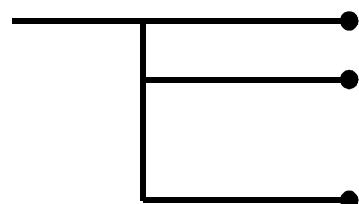
*economic
costs/benefits*

social context

*information
context*

Data Sources

demographics



assessor data (housing)

survey data (education, income,
political affiliation)

census data (distribution)

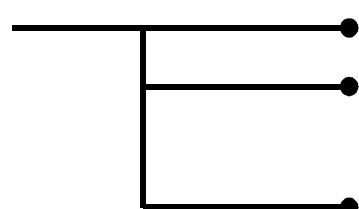
***economic
costs/benefits***

social context

***information
context***

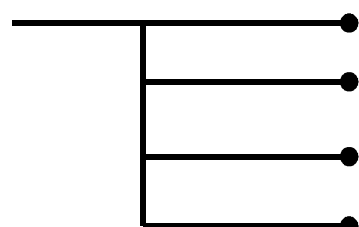
Data Sources

demographics



- assessor data (housing)
- survey data (education, income, political affiliation)
- census data (distribution)

economic costs/benefits



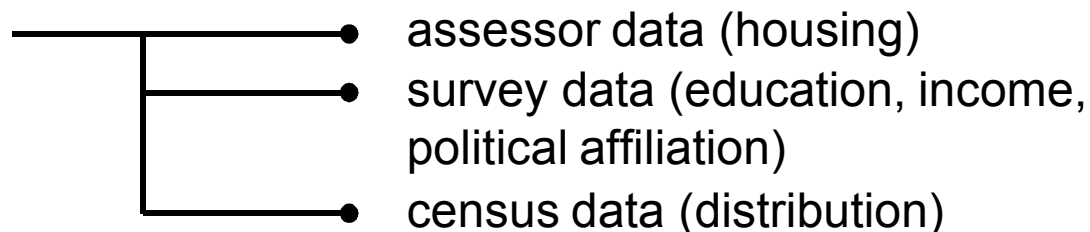
- CSI data
- electricity use/price data (NREL; utility)
- economic data (GDP)
- experiments (online/field)

social context

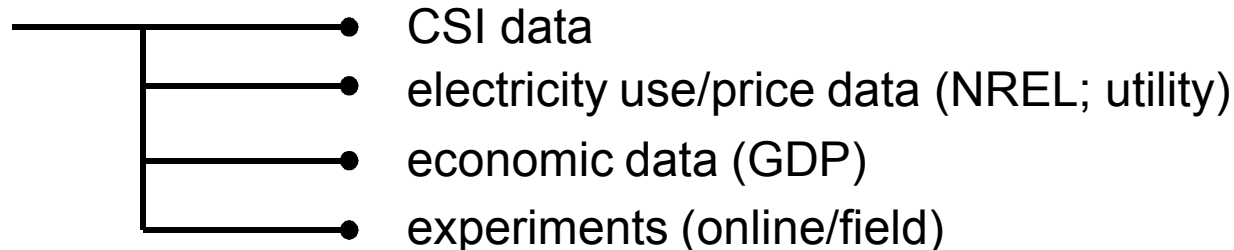
information context

Data Sources

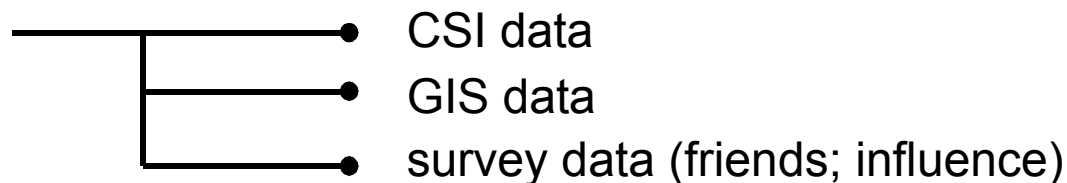
demographics



economic costs/benefits



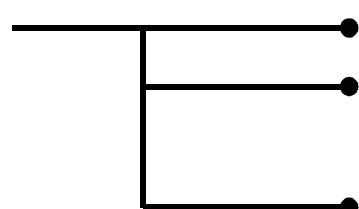
social context



information context

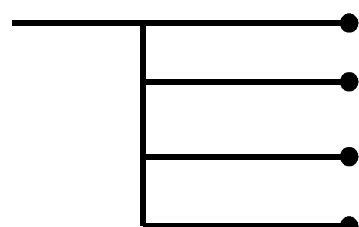
Data Sources

demographics



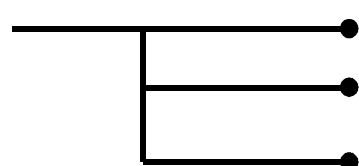
- assessor data (housing)
- survey data (education, income, political affiliation)
- census data (distribution)

economic costs/benefits



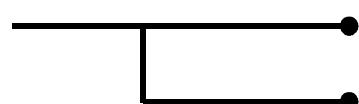
- CSI data
- electricity use/price data (NREL; utility)
- economic data (GDP)
- experiments (online/field)

social context



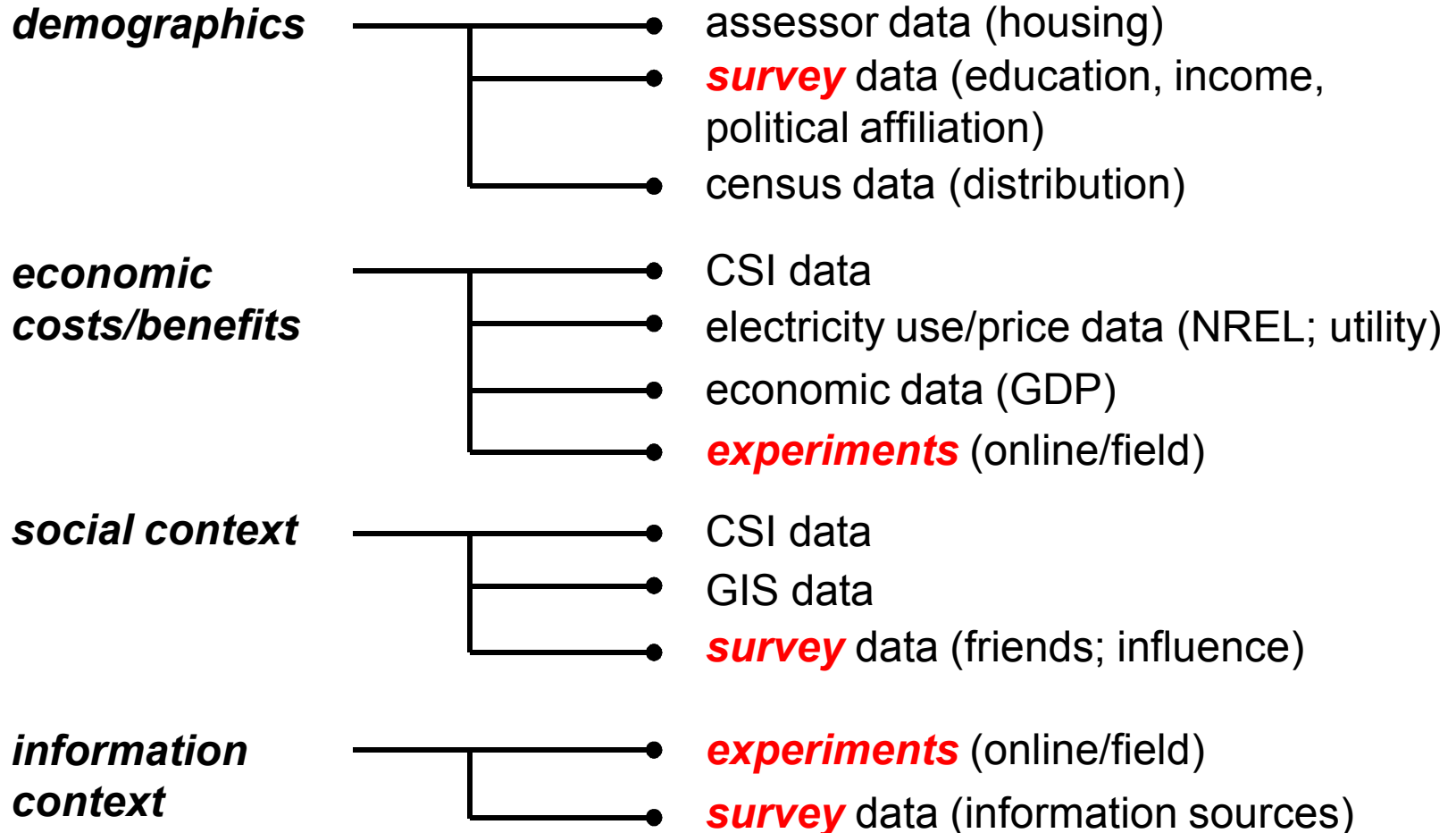
- CSI data
- GIS data
- survey data (friends; influence)

information context

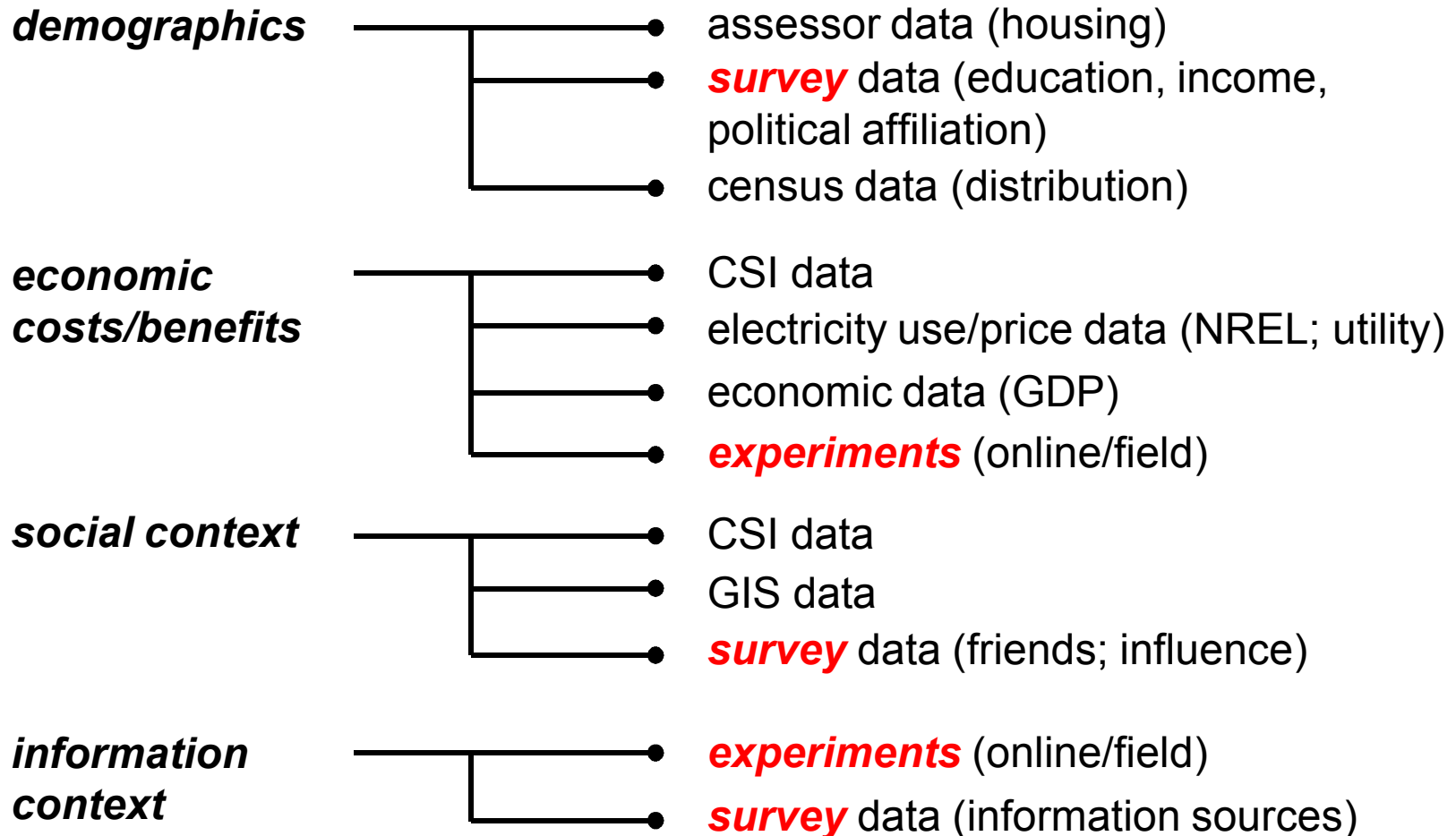


- experiments (online/field)
- survey data (information sources)

Data Sources: **Our Project**



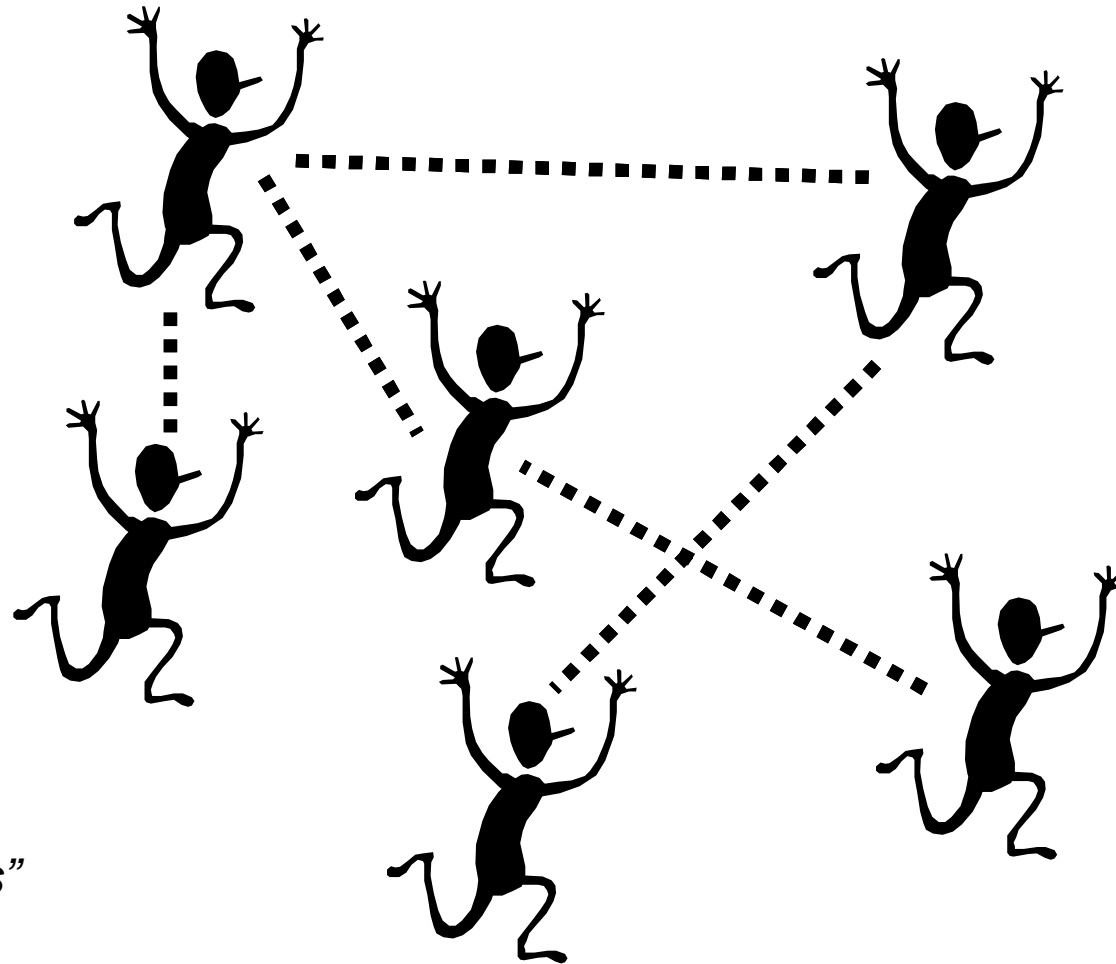
Data Sources: **Our Project**



more on that later...

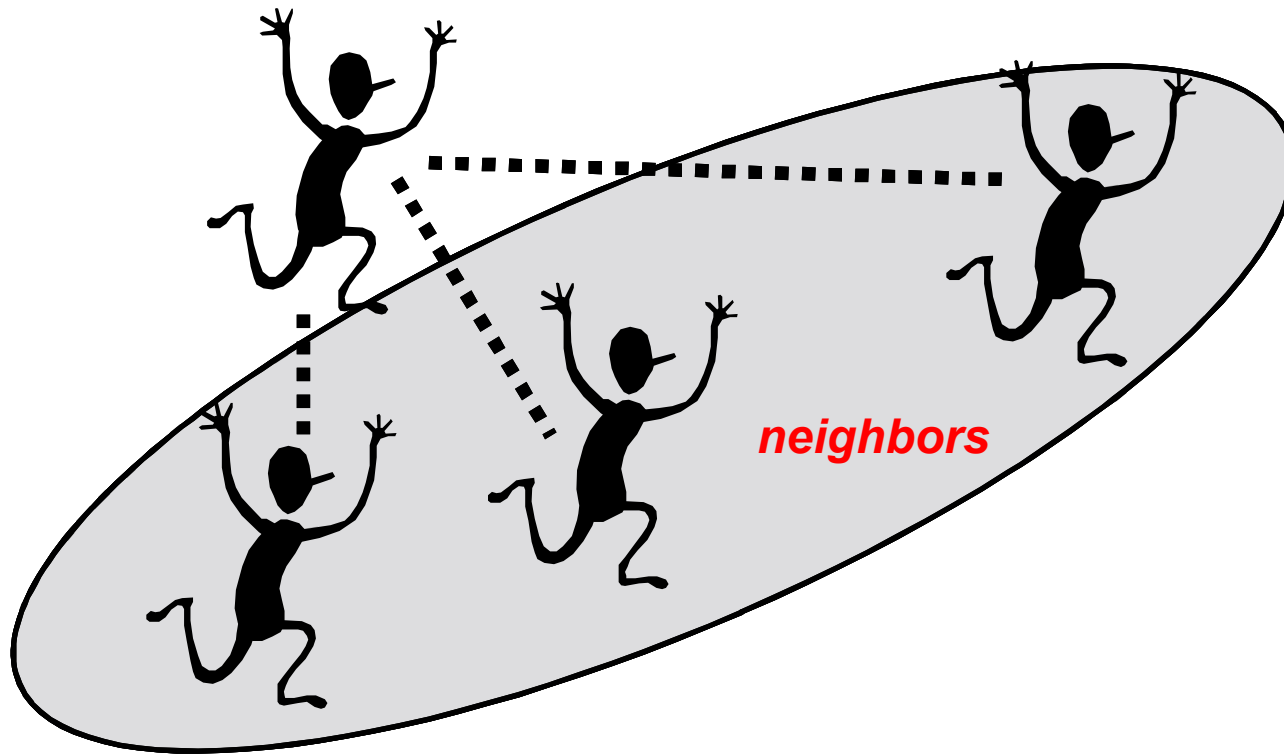
The Agent Based Model, Social Influence, and Adoption Dynamics

Agent-Based Model

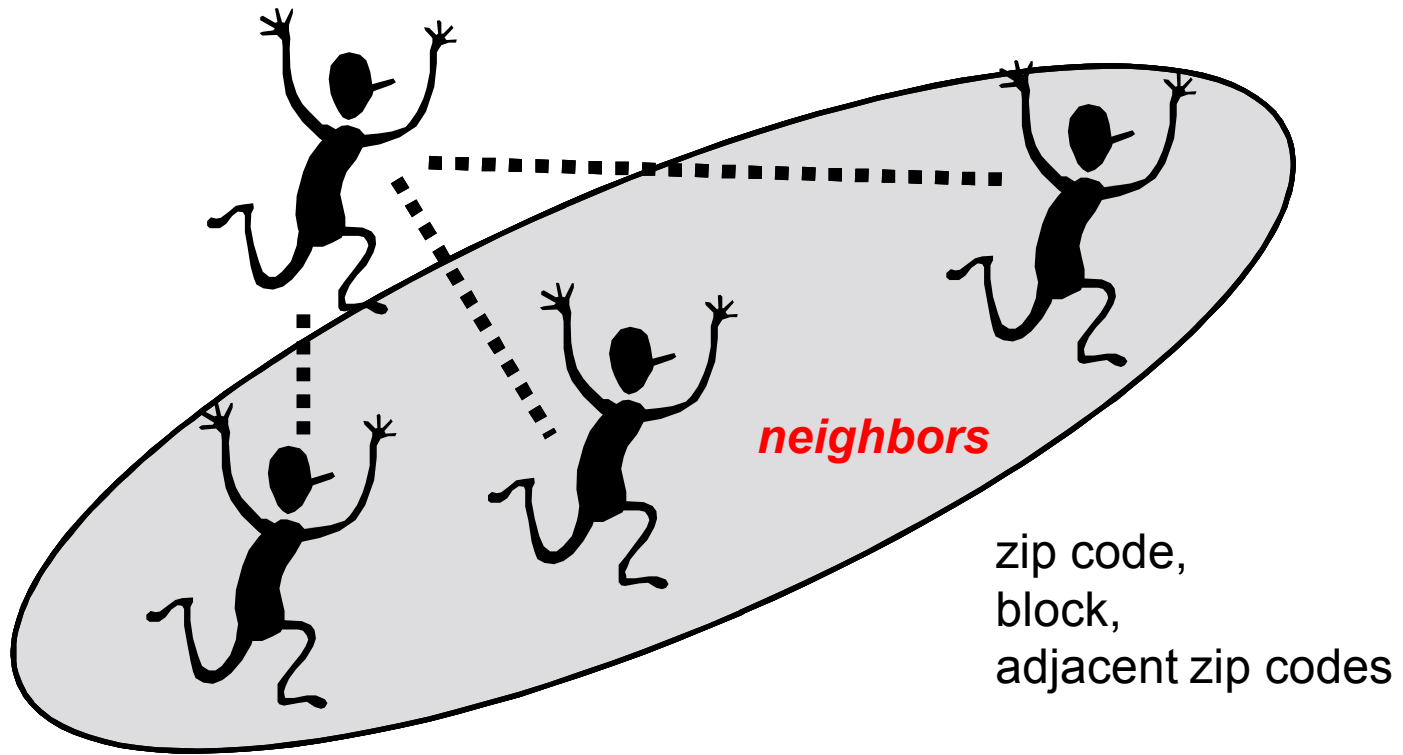


*Agent “interactions”
driven by social
influence and visibility*

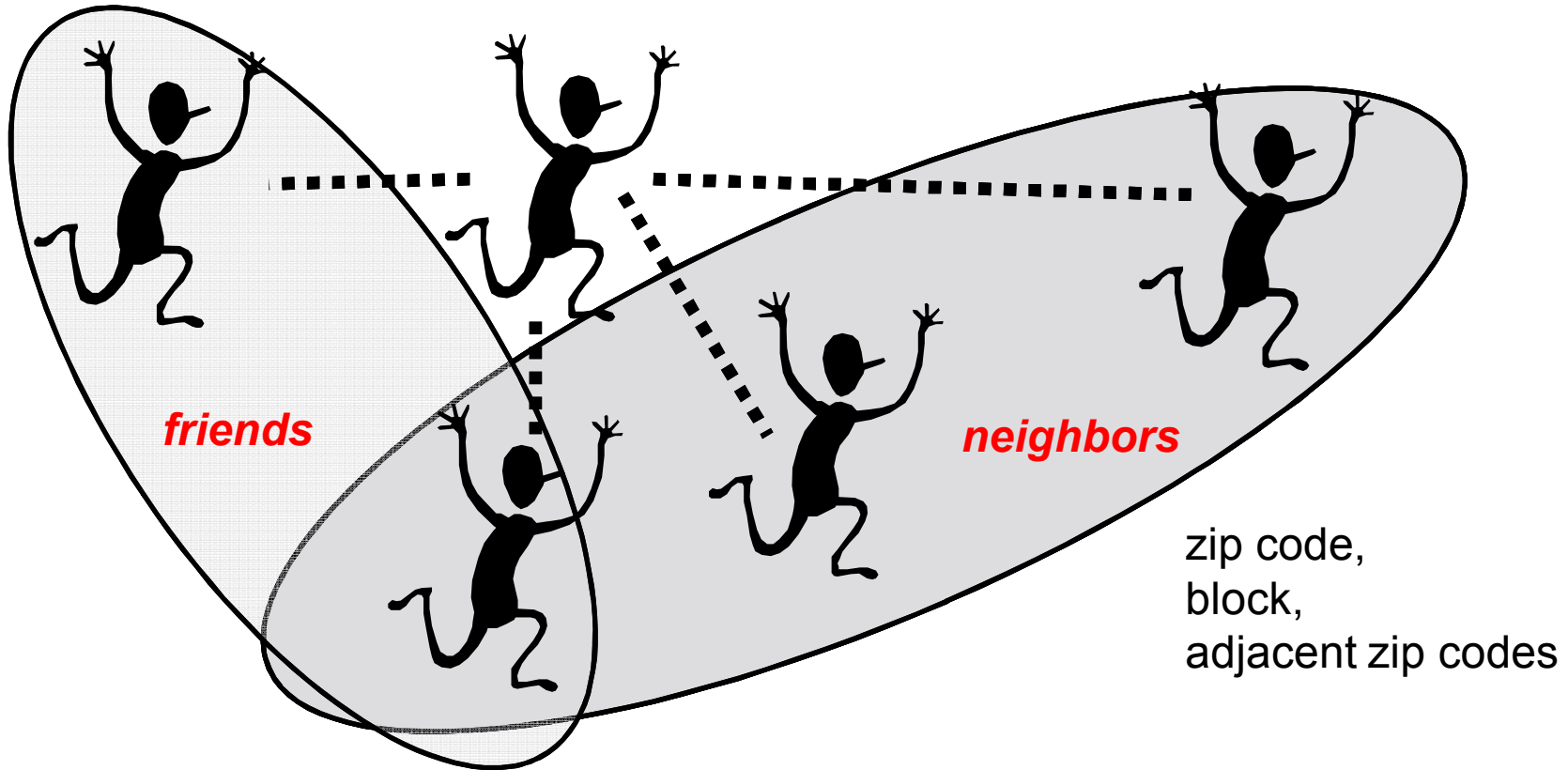
Agent-Based Model



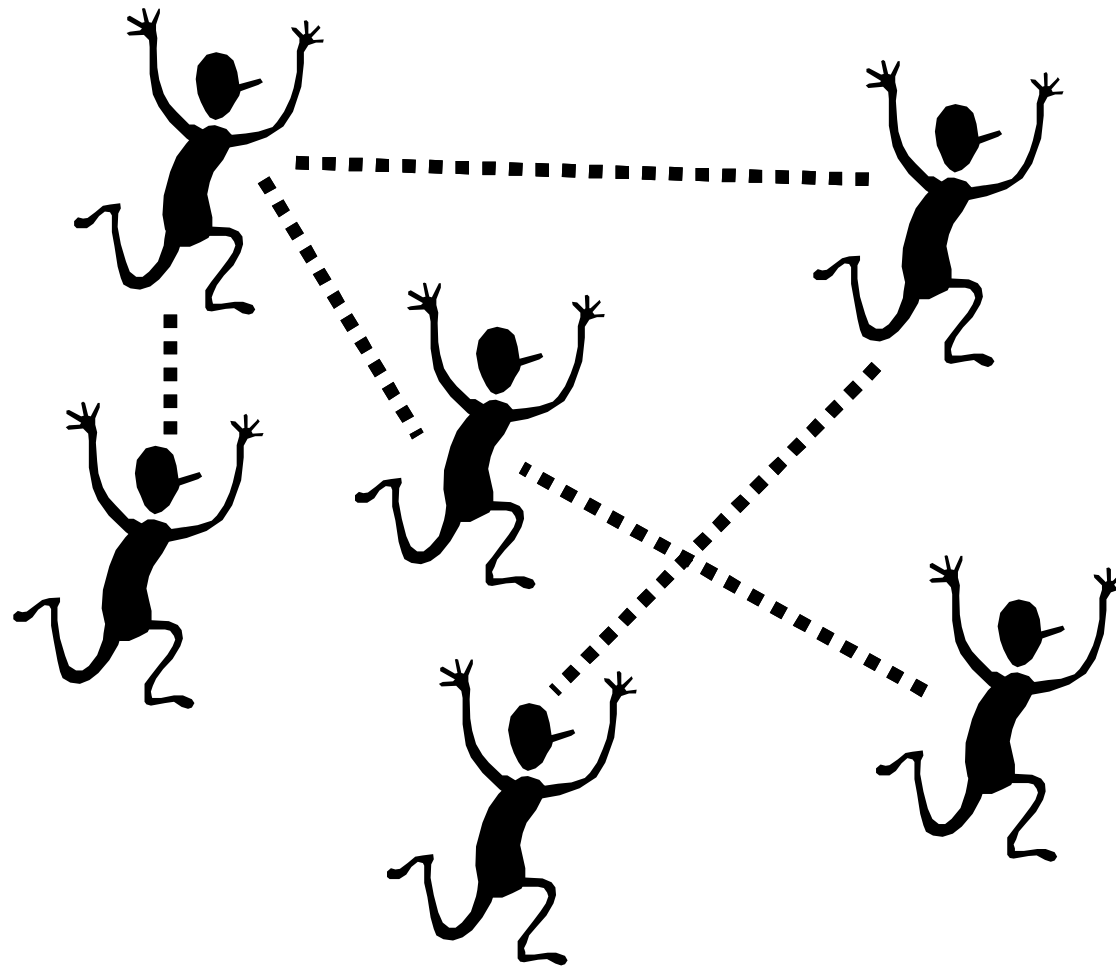
Agent-Based Model



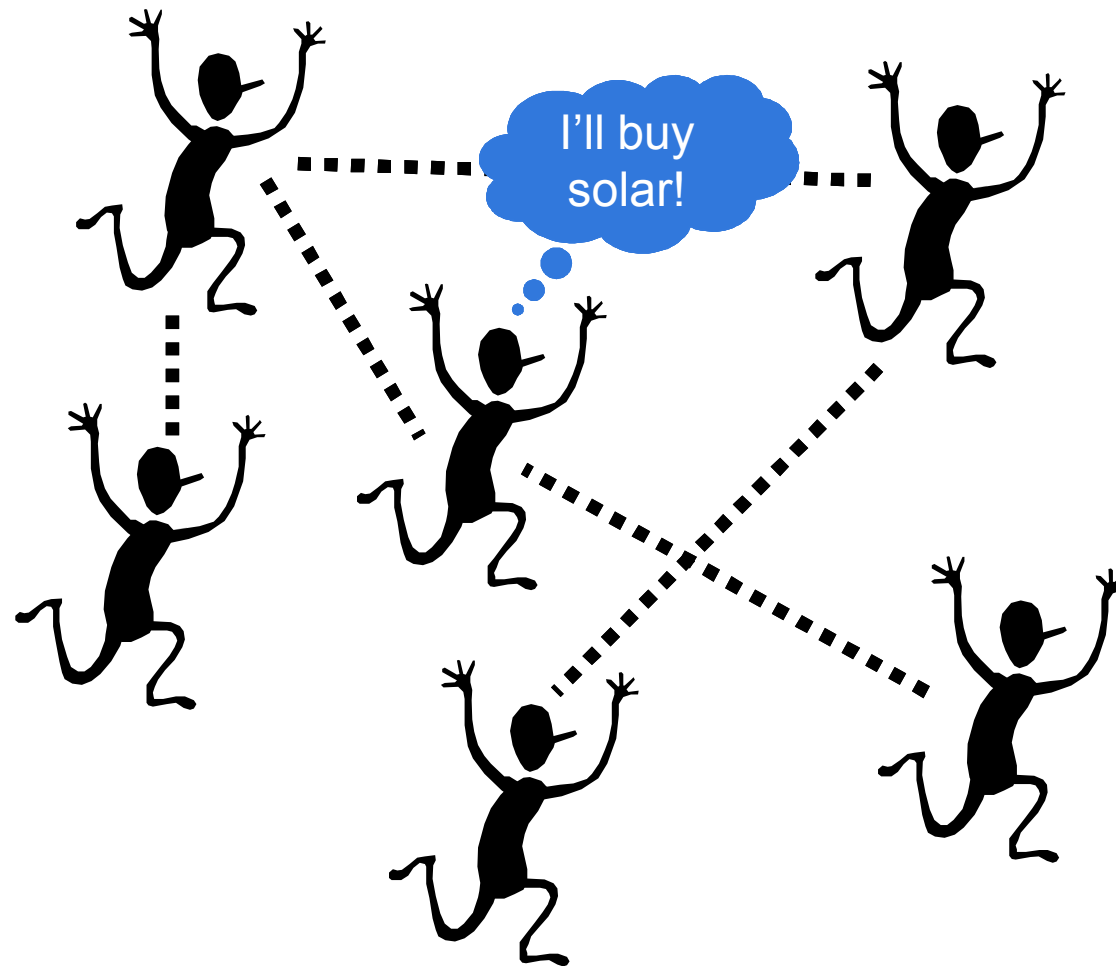
Agent-Based Model



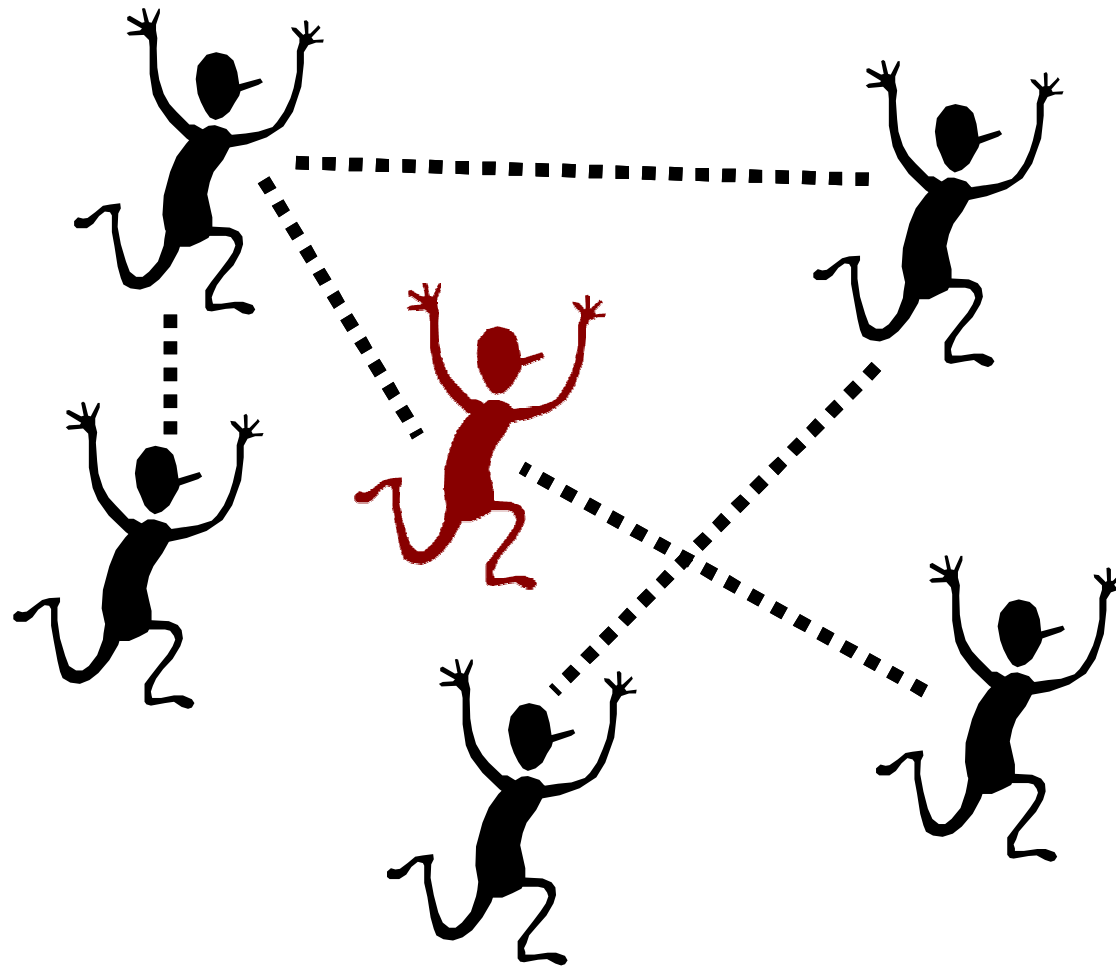
Social Influence and Diffusion



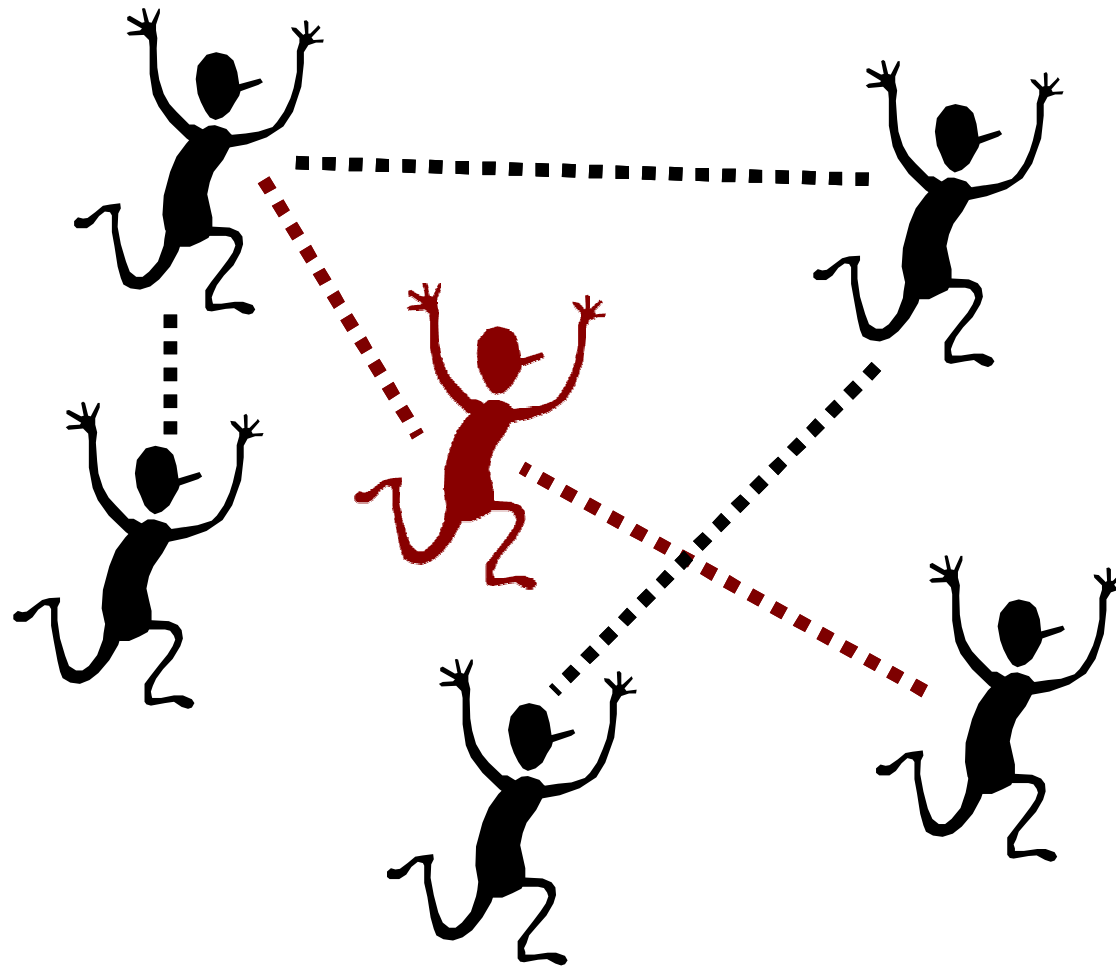
Social Influence and Diffusion



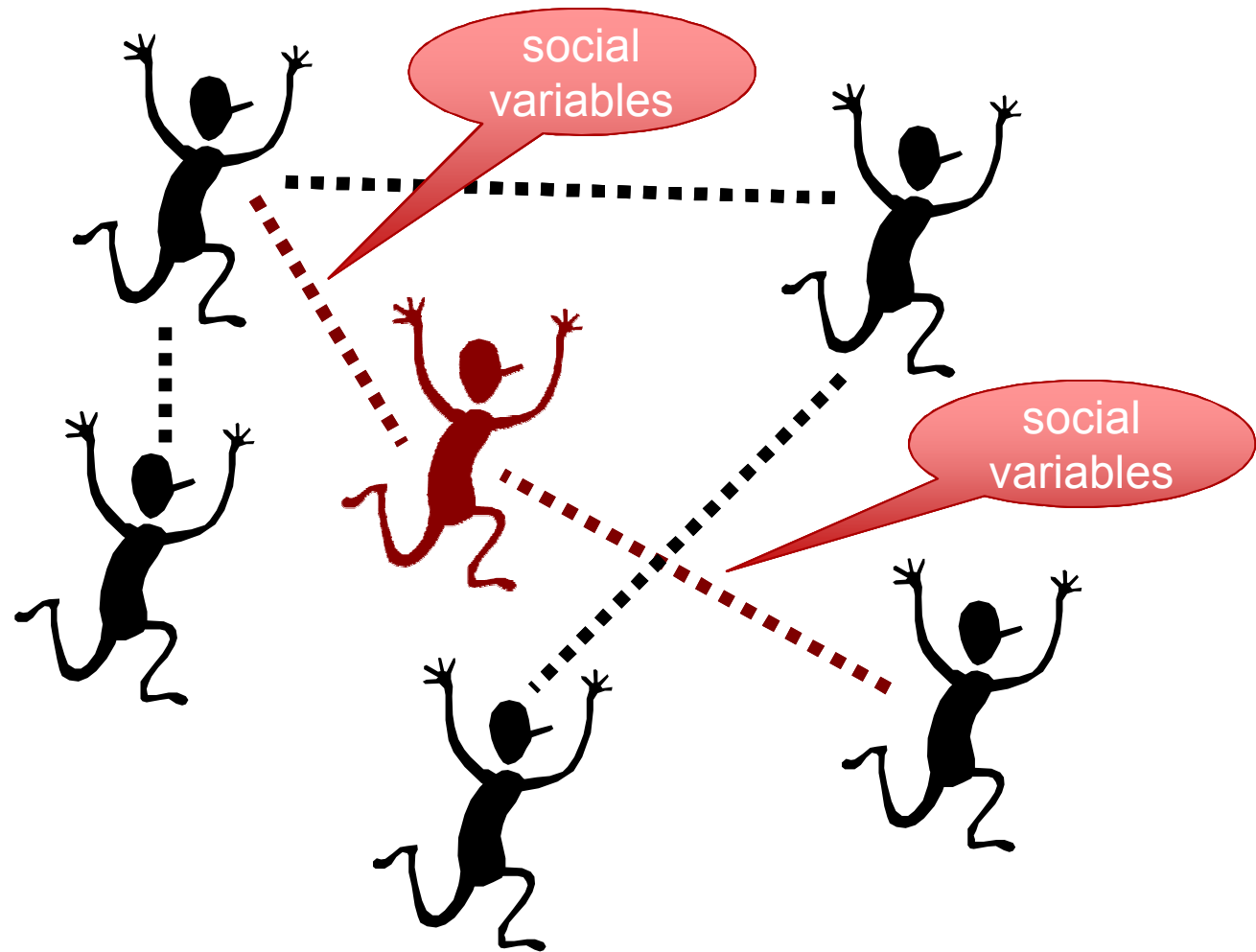
Social Influence and Diffusion



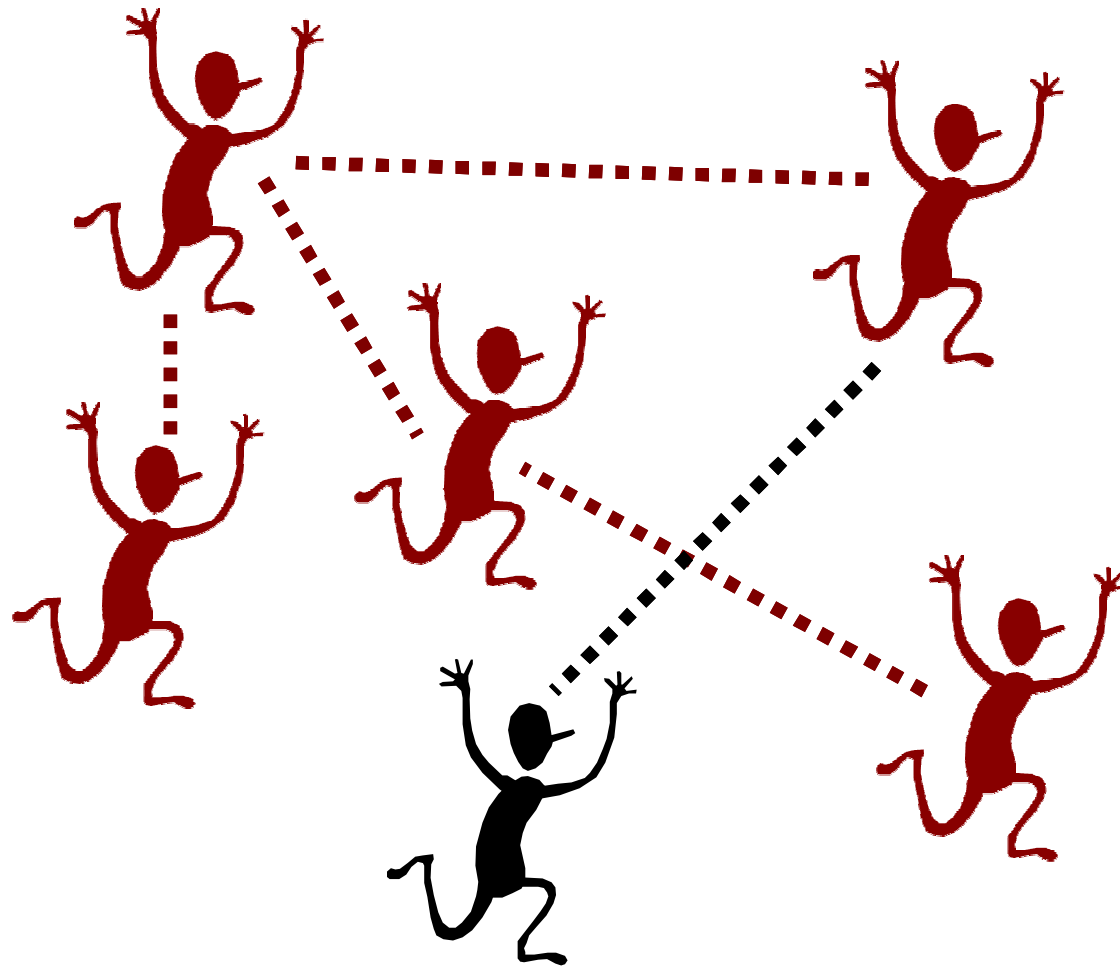
Social Influence and Diffusion



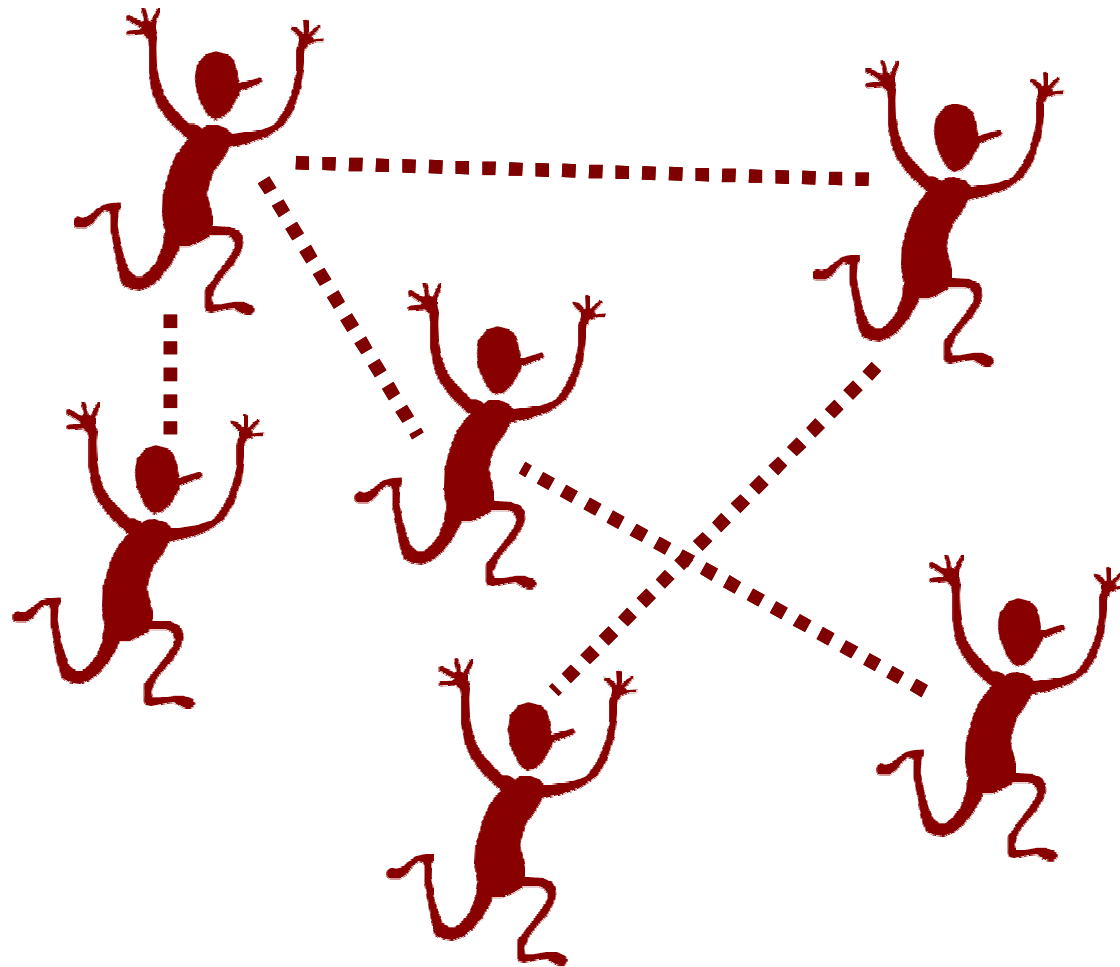
Social Influence and Diffusion



Social Influence and Diffusion



Social Influence and Diffusion



Policy Analysis via Dynamic Optimization

Predictive Model... Now what?



Predictive Model... Now what?



what kinds of incentives?

Steering PV Adoption

incentives



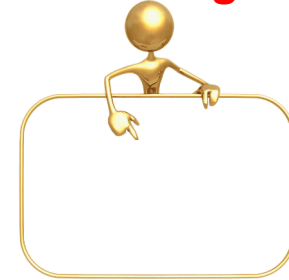
CSI incentives
Federal incentives
Tax rebates

information



CCSE/DOE website
(information)
Installer website

framing



Savings vs. "green" vs.
energy independent

Dynamic Optimization

Dynamic Optimization

observe “state of the world”

of adopters in each zip code

Dynamic Optimization

observe “state of the world”

of adopters in each zip code



choose a policy

incentives, information campaign, framing of information

Dynamic Optimization

observe “state of the world”

of adopters in each zip code



choose a policy

incentives, information campaign, framing of information



new “state of the world”

Dynamic Optimization

observe “state of the world”

of adopters in each zip code



choose a policy

incentives, information campaign, framing of information



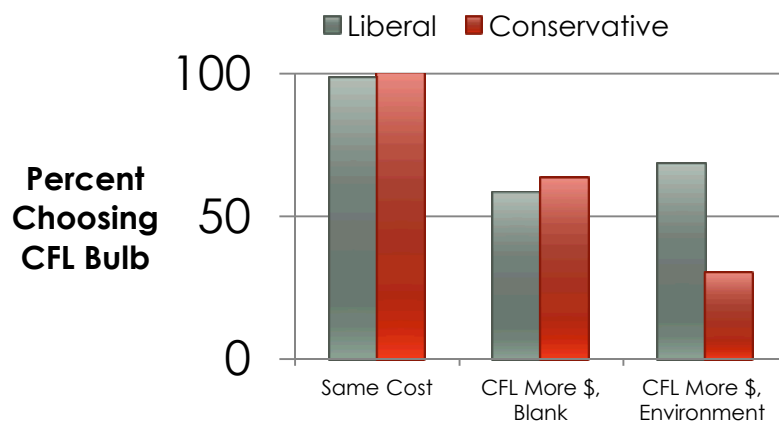
new “state of the world”

Goal: compute “optimal policy” (the best thing to do in any state)

Experiments

Controlled Experiments

- Investigate **causal** effect of financial *and* social factors on individual PV adoption
- Importance of financial incentives well-established
- New evidence for importance of social “(dis)incentives” in energy decision-making
 - Peer effects (Bollinger & Gillingham, 2012)
 - Personal values (Gromet, Kunreuther, & Larrick, 2013)



Overview of Experiments

- Aim: Examines effect of financial and social incentives, and how they interact, on individual adoption of PV
 - Social: How PV is framed and how it corresponds with individuals' values
- Pilot Studies
 - Sample: Homeowners from pre-specified geographic areas in the US
 - Participants are recruited and complete experiments online
 - Examines different decision steps
- Field Studies
 - Uses insights from controlled pilot studies to design field studies of individual adoption

Overview of Experiments

- PV framed in one of three ways:
 - Money Frame (Reducing utility bills)
 - Environmental Frame (Reducing carbon emissions)
 - Independence Frame (Reducing reliance on utility companies)

- Personal Values
 - As determined by political ideology/affiliation

- Presence and type of financial incentives

- Decision Steps:
 - Willingness to:
 1. Spend time learning about PV home installation
 2. Spend time getting bids from contractors
 3. Sign-up/pay for solar installation

Surveys

Survey

- Several iterations on the survey instrument
- Questions about:
 - Attitude towards PV
 - Information/exposure
 - Peer effects
 - Factors important to the adoption decision
 - Economic benefits/costs, risk, attitudes towards the local utility, control, etc
 - Difficulty of obtaining good information
 - Demographics
- Questions design to apply both to adopters and non-adopters
 - Will target the same groups as in the focus group design
 - Help distinguish adopters from (different types of) non-adopters

- *Sandia National Laboratories*
 - Yevgeniy Vorobeychik, Ph.D., PI
 - **Research expertise:** technology diffusion modeling, applied machine learning, optimization, behavioral network economics
 - Kiran Lakkaraju, Ph.D.
 - **Research expertise:** machine learning, cognitive modeling, agent-based modeling
 - Joshua Letchford, Ph.D.
 - **Research expertise:** computational modeling and analysis
 - Jaideep Ray, Ph.D.
 - **Research expertise:** Bayesian inference, uncertainty quantification
 - Ali Pinar, Ph.D.
 - **Research expertise:** large-scale social network analysis

Team

- University of Pennsylvania (Wharton)
 - Professor Howard Kunreuther, Ph.D.
 - **Research expertise:** behavioral economics, policy
 - Professor Ruben Lobel, Ph.D.
 - **Research expertise:** dynamic optimization, solar energy policy, behavioral modeling
 - Professor Arthur van Benthem
 - **Research expertise:** economics of solar energy diffusion
 - Karen Campbell, Ph.D.
 - **Research expertise:** analysis of macroeconomic factors
 - Dena Gromet, Ph.D.
 - **Research expertise:** psychology, online/lab experiments

Team

- California Center for Sustainable Energy
 - Timothy Treadwell, Georgina Arreola
 - **Research expertise:** program design and implementation, data analysis
- National Renewable Energy Laboratory
 - Easan Drury
 - **Research expertise:** solar energy policy, data analysis, computational modeling

Project Goals

- *Data Analysis*
 - Identify potential factors, and rank them in order of importance for individual adoption decisions
- *Data Collection*
 - Deploy and analyze survey of adopters and non-adopters
 - Small focus groups, considering adopters and different groups of non-adopters
 - Online/lab/field pilot experiments
- *Computational Modeling*
 - Individual-level model
 - Predict probability of adoption, conditional on available features
 - Agent-based model
 - Predict aggregate adoption trends, conditional on available (global) features
 - Use available, and collected data to calibrate and test the models