Models of Human Cognition and Human Networks: Integration & Scaling Up to Multiple Actors

Task 5: Trust, Influence, Modeling & Enhancing Human Performance (TIME)
Rev1.2

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Game Environment: IED Adversarial Game

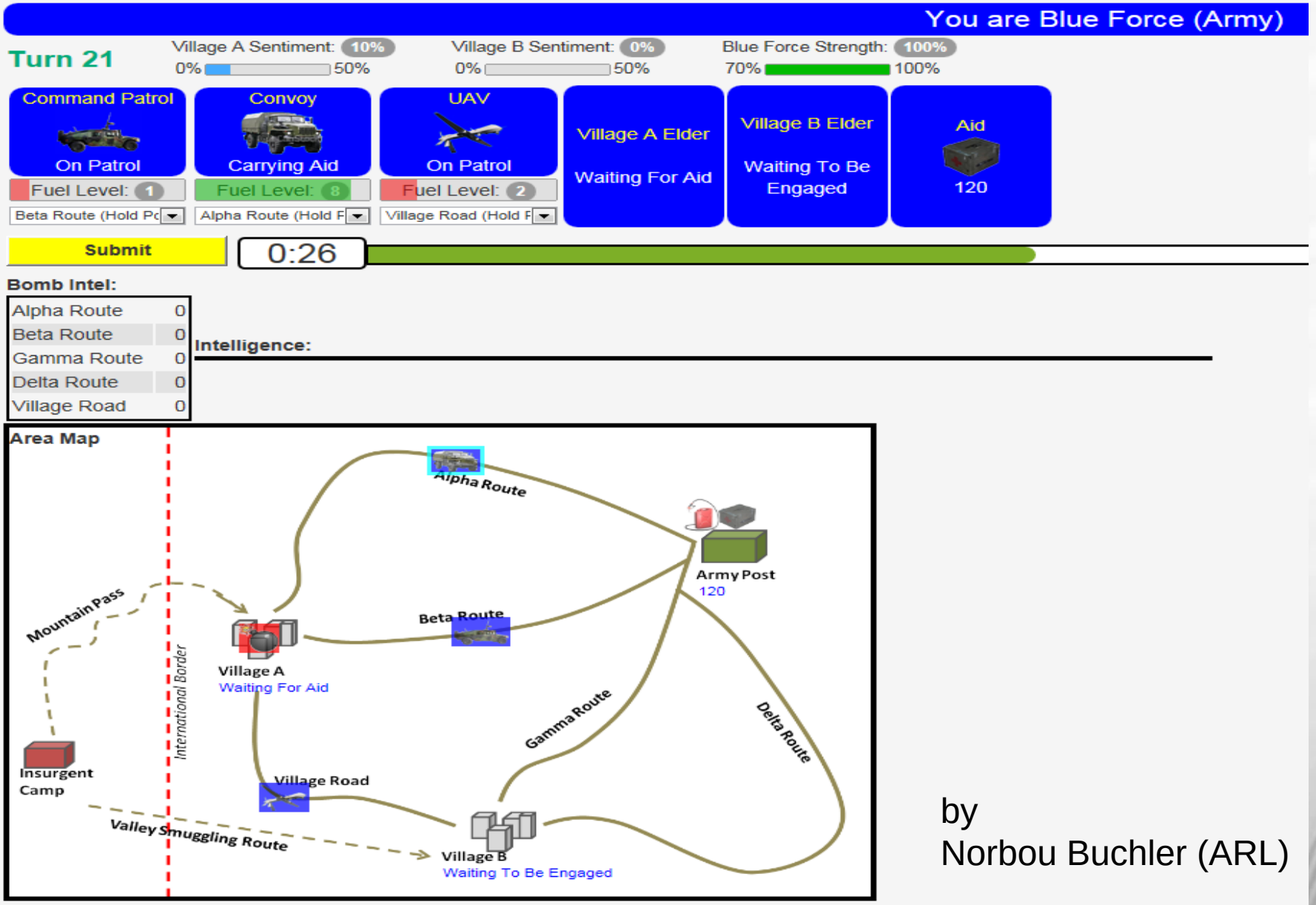
Adversarial game: Blue Force (good guy) vs Red Network (enemy)

Civilian villagers who must be won over

Both sides want to (1) attack the other side and (2) won over population

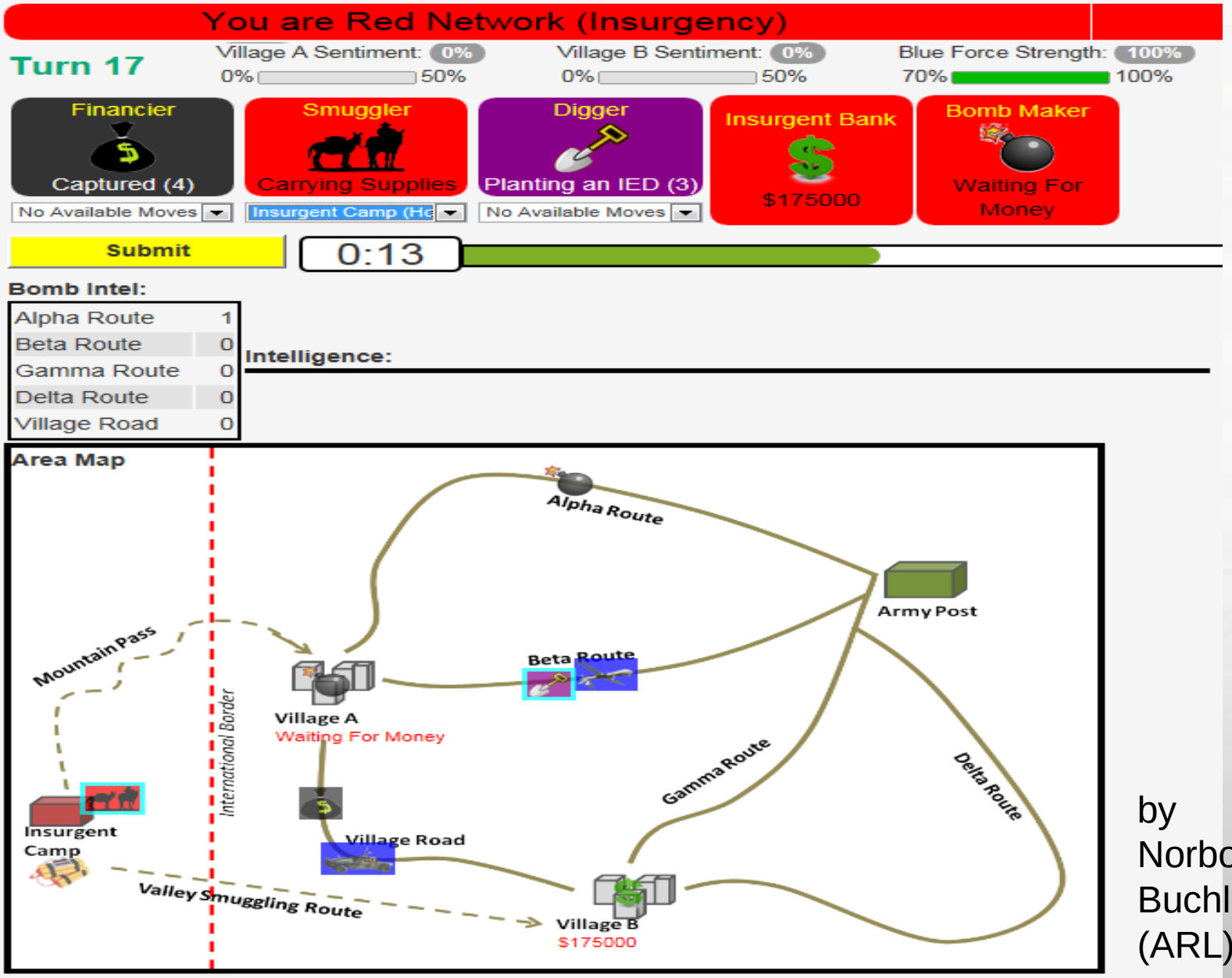
IED Game is played as 1 person vs 1 person take-turn plays, but can be extended to multiple persons vs multiple persons concurrent plays

Game Interface: Blue Force



by
Norbou Buchler (ARL)

Game Interface: Red Network



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Agents, Resources, and Routes

Blue Force's Agents:

(1) Commander
(2) Convoy, carrying aid
(3) Radio Operator

Resource: aid for villagers

Villagers:

(1) Village 1 Elder
(2) Village 2 Elder

Red Network:

(1) Financier
(2) Bomb maker
(3) Smuggler
(4) Digger

Resource: money for bombmaking and logistics

Routes:

(1) Alpha Route
(2) Beta Route
(3) Gamma Route
(4) Delta Route
(5) Mountain Pass
(6) Valley Route

Places:

(1) Army Post
(2) Insurgent Camp
(3) Village A
(4) Village B

Agents with Cognitive & Network Modeling

Cognitive Architectures:

(1) Can model individual human (nodes in the network) cognitive performance and processes—and 1 vs 1 games

(2) But mostly applied to individual cognition—not "networked cognition" in human groups

Social Networks:

(1) Can model the interactions (edges in the network) among people—in *N* vs *N* games

(2) But do not have good cognitive consideration of individual persons (dumb nodes)

From 1 vs 1 to N vs N: Network Emergence

Networks among people emerge when each side has more than 1 player → *N* players for each side, with different roles (the larger *N* the better).

Blue Force's agents:

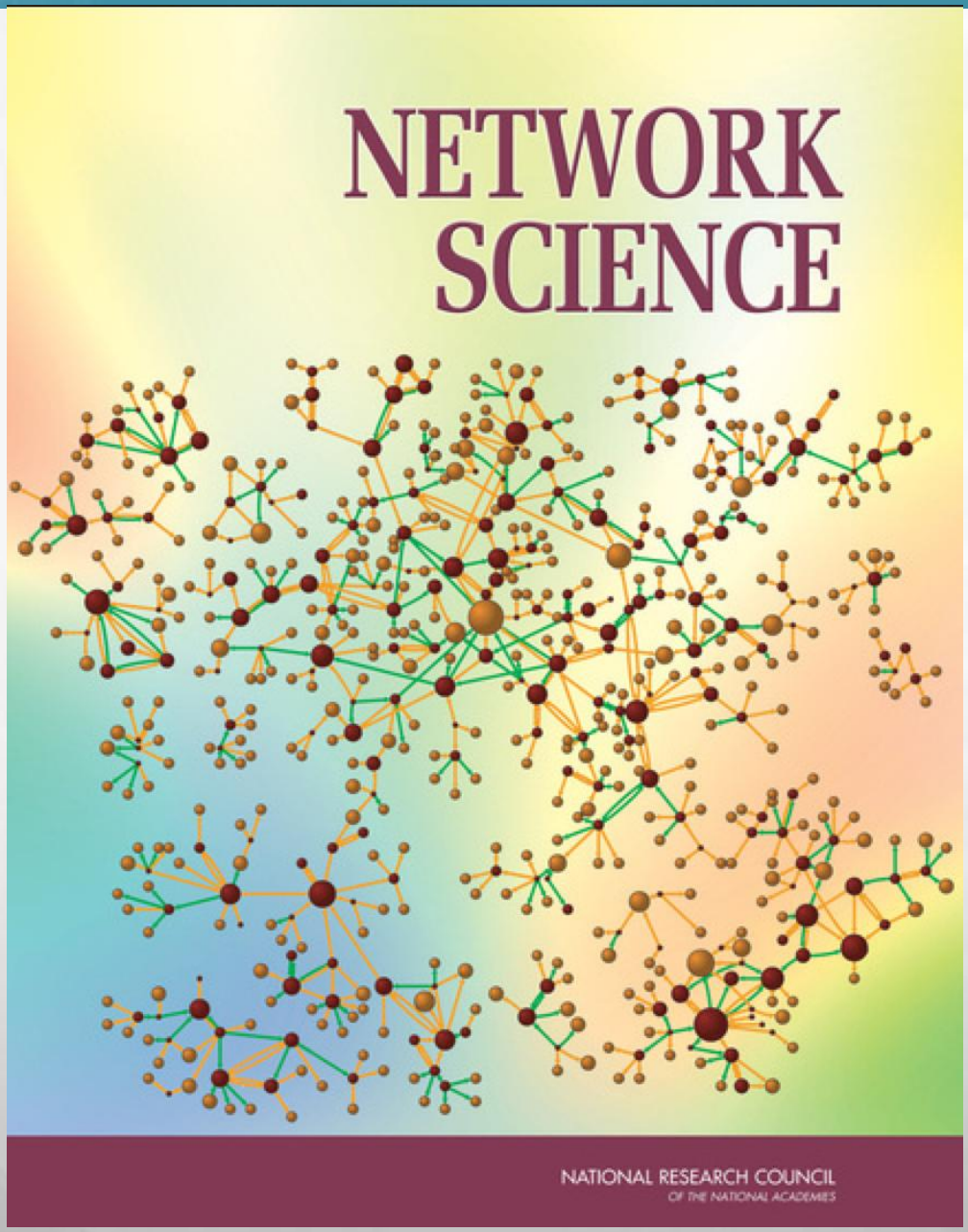
commander, convoy patrol, and radio operator.

Red Network's agents:

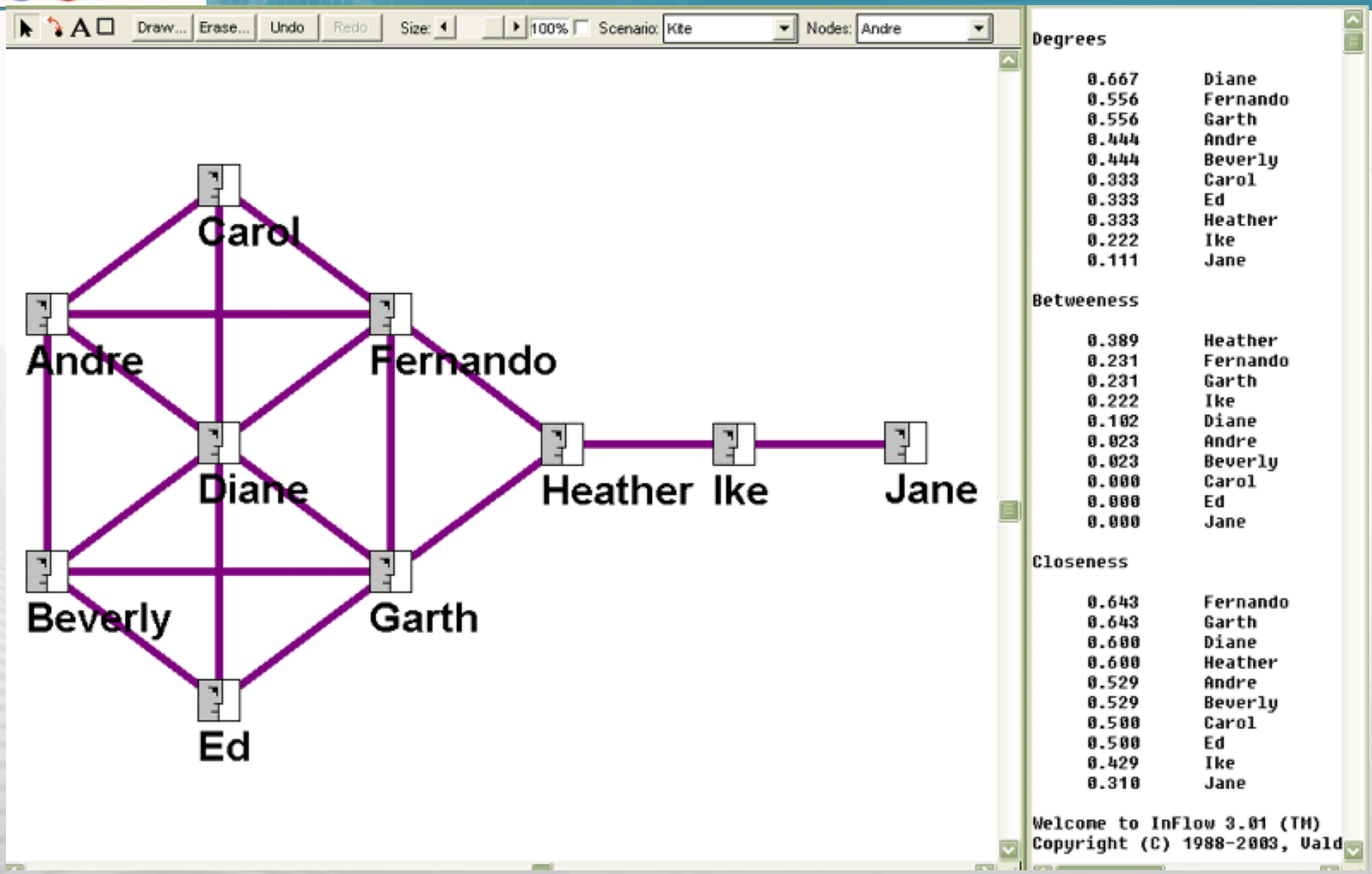
financier, bomb maker, smuggler, and digger.

Network Science

Interdisciplinary research to understand the structures and dynamics of networks, e.g., human social networks



Network Structure and Analysis



Kite Network by David Krackhardt CMU

Network Drivers

Network drivers:

Social processes that underlie the formation, maintenance,

and dissolution of relationships

(1)Activity Foci: places and times conducive for the formation of networks (e.g., a village where villager with Blue Force)

(2)Structuration: formation of structure by manifested interactions (e.g., a bombmaker finding the financier)

(3)Homophily: people interact with others with similar features and interests (e.g., bombmaker with bombmaker)

(4)Information seeking: people interact with others having needed information (e.g., digger with financier)

(5)Exchange: people interact with others to exchange values and goods (e.g., commander having aid with village elder)

Note: in ACT-R we create multiple chunks representing multiple agents

Activity Foci

- Places, social situations, and times encouraging the formation of networks (activity foci)
  - Army Command Post: shared activities involving Intelligence Analyst, Operations, Fire Support Team, and Signal Specialist
  - Convoy Patrol: shared activities involving patrol leaders, patrol members, and radio telephone operators
  - Insurgent Camp: shared activities among insurgents, where experience shapes insurgent skills

Activity Foci Algorithm

- For each agent,
  - Search for shared activities (activity foci)
    - shared times, places, and relationships
  - For each activity focus
    - Execute the activity
    - Record what changed in ego-network and environment

Activity Foci: ACT-R

An activity focus based on location:

- Put locations as chunks in declarative knowledge slots
- Retrieve chunks with same locations
- For those chunks, have the agents in the slots interact with each other by creating a paired interaction (Interact agent1 agent2) chunk into the retrieval buffer

An Activity Focus: ACT-R Code

```
(define-model        activityfocus1location
(chunk-type agent-loc agent location)
(chunk-type loc-match startlocation endlocation)
(chunk-type interact agent1 agent2)
(define-chunks  (name1 ISA agent-loc agent digger location camp)
            (name2 ISA agent-loc agent financier location camp)
            (name3 ISA agent-loc agent bombmaker location village)
            (name4 ISA agent-loc agent smuggler location valleyroad)
            (first-goal ISA loc-match startlocation camp endlocation camp)
(p start
            =goal>
                        ISA         loc-match
                        startlocation          =loc1
            ==>
            +retrieval>
                        ISA         agent-loc
                        agent       =ag1
                        location    =loc1    )
```

ACT-R Code (cont.)

```
(p increment
        =goal>
                ISA             loc-match
                startlocation           =loc1
                endlocation             =loc1
        =retrieval>
                ISA             agent-loc
                agent           =ag2
                location        =loc2
        ==>
        =goal>
                ISA             loc-match
                endlocation             =loc2
        +retrieval>
                ISA             agent-loc
                location        =loc2
        =retrieval>
                ISA             interact
                agent1          =ag1
                agent2          =ag2   )
```

```
(p stop
        =goal>
                ISA             loc-match
        -               endlocation =loc1
        ==>
        -goal>
)

(goal-focus first-goal)
)
```

Structuration

The formation of a network (network structuration) occurs through

1. reticulation (of links as resources),
2. activation (choosing a link to act upon influenced by shared activities), and
3. enactment (use of the link). The enactment in turn affects the links availability as resources.

Structuration Algorithm

- For each agent
  - Inventorize available links (connections in its ego-network) as resources
  - Rank order the links as to their saliency and usefulness
  - Activate (choose) a link by making a decision related to a goal or based on heuristics
  - Use the link or manifest the link by action, affecting the ego-network and the environment

Structuration: ACT-R

- Put an agent's ego-network nodes as chunks into its own Imaginal Buffer
- Have an agent choose another agent to interact
- Do the interaction, and harvest the Imaginal Buffer and put into Retrieval Buffer, forming network structure as chunks in declarative knowledge
  - E.g., a commander forms a bond with his convoy patrolmen after an interaction

Information Seeking

- Agent looks for others having a piece of information it needs
- Agent however may not know the ground-truth about who-knows-what, so it may rely on perceived who-knows-what

Information Seeking Algorithm

- For each agent,
  - Rank order other agents for the piece of information it needs
    - Actual ranking based on ground-truth if known
    - Perceived ranking
  - Decide which agent to ask based on the rank order
  - Communicate with the chosen agent
  - May exchange resources for the information

Information Seeking: ACT-R

- Put known information as chunks for each agent
- For each agent, set the goal of getting a new information from other agents
- Retrieve chunks about agent's information from other agents
- If the chunk information is not the same as own information, add the information to own declarative knowledge
  - E.g., A digger seeks information about financing for digging tools from a financier

ACT-R Code

```
(define-model     informationseeking
(chunk-type agent-info     agent information)
(chunk-type info-match startinfo endinfo)
(define-chunks  (name1 ISA agent-info agent digger information digtooling)
          (name2 ISA agent-info agent financier information financing)
          (name3 ISA agent-info agent bombmaker information bombmaking)
          (first-goal ISA info-match startinfo financing endinfo digtooling)
(p start
          =goal>
                    ISA        info-match
                    startinfo              =info1
          ==>
          +retrieval>
                    ISA        agent-info
                    agent     =ag1      information         =info1)
```

ACT-R Code (Cont.)

```
(p increment
        =goal>
                ISA         info-match
                startinfo   =info1
                endinfo     =info1
        =retrieval>
                ISA         agent-info
                agent       =ag2
                information             =info1
        ==>
        =goal>
                ISA         info-match
                endinfo     =info2
        +retrieval>
                ISA         agent-info
                agent       =ag1
                information             =info2
)
```

```
(p stop
        =goal>
                ISA   info-match
                endinfo =info1
        -
        ==>
        -goal>
)

(goal-focus first-goal)
)
```

Homophily

- Agent interacts with others based on similarity in features or group identity (e.g., cadets with cadets)
- The result of the interaction might lead to the forming of stronger bonds or relationships, which in turn leads to more interactions in the future

Homophily Algorithm

- For each agent,
  - Rank order other agents in its ego-network based on feature similarity
  - Decide which agent to communicate with based on the rank order
  - Act on the decision
  - Record what changes in ego-network and environment

Homophily: ACT-R

- Put features as chunks in declarative knowledge for each agent
- For each agent, retrieve feature chunks from other agents or from own Imaginal Buffer
- If the other agent's retrieved chunks are the same or similar enough (by enabling subsymbolic computation (sgp :esc t), then have the agent interact with this agent
  - E.g., a convoy patrolman interacts with another convoy patrolman who has traversed Route Gamma he is about to traverse.

Social Exchange

Social Exchange Theory:

Agent's outcome of social interactions

is related to the exchange of resources (material goods, services, and social values) during interactions

The outcome is calculated by subtracting the costs from the benefits of the exchange.

Social Exchange Algorithm

- For each agent,
  - Go through each other agent in its ego-network and inventorize the resources that are exchangeable
  - For each pair of exchangeable resources, calculate the cost and benefit of the exchange
  - Decide on some criteria whether to exchange a pair of resource
  - Act on the exchange decision
  - Record what changes in ego-network and environment

Social Exchange: ACT-R

- Put goods (or valuables) as chunks in agent's declarative knowledge
- For each agent, compute the value of goods belonging other agents in its ego-network
- If the other agent's goods has greater benefit than cost, then have this agent interact with the other agent.
  - E.g. a bombmaker interacts with a financier when the financier pays much more money than the cost of material, labor, and risk in making a bomb

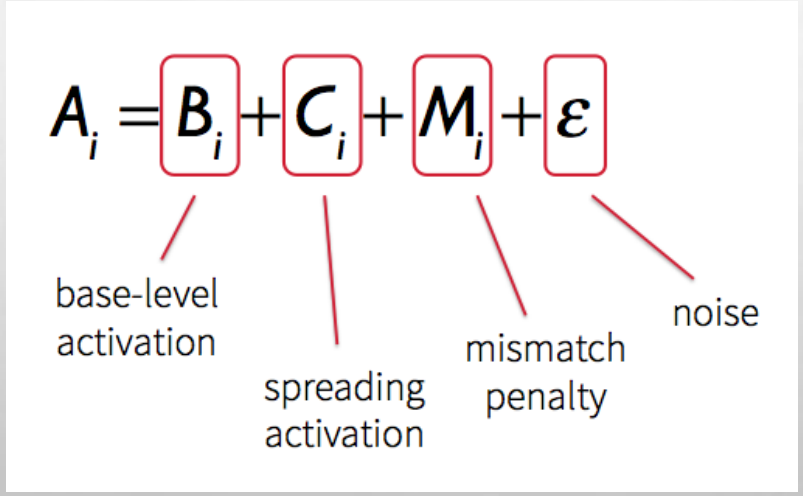
Dynamic Bayesian Networks

- Dynamic Bayesian Network (DBN) models the decision making from complex interdependencies of many variables
- DBN models individual agent's decision making for each of the social drivers
  - Learning from empirical data
- DBN models individual agents' combined decision for ***all*** of the social drivers (homophily, information seeking, structuration, exchange, and activity foci) at a particular time interval.

DBN Modifies ACT-R

Activation--with Dynamic Bayesian Network, the activation (and partial matching) will spread differently:

- not based on similarity between chunks, but
- based on the strength of Bayesian Network edge between two chunks, *possibly* by modifying the spreading activation *C* or adding new "network influence" term *N*.
- *could* also modify production utility via Dynamic Bayesian Networks learning



Example of DBN ACT-R

For Homophily, e.g., DBN nodes are chunks (feature1 school CMU),

(feature2 cognitivearchitecture ACTR),

(feature3 cognitivearchitecture Soar)

Here feature1 and feature2 have positive correlation, but not with feature3 as Soar is correlated with University of Michigan

Model Checking

- Model Checking could provide proofs-of-correctness & counter-examples.
- PRISM http://www.prismmodelchecker.org/
  - checking the probabilistic behaviors (and activation) of each agent and its ego-network
- PRISM-games http://www.prismmodelchecker.org/games/
  - checking the correctness of the adversarial IED Game and gameplays.

Acknowledgments