How do you approach and solve problems?

The Cognitive Biometric of Unconscious Strategy Patterns in Covert Games

SOUTHWEST RESEARCH INSTITUTE® (SwRI®)

Smart Card Alliance Conference

John Carrola, Presenter
Jenifer Wheeler and Denise Varner, PhD, Co-Principal Investigators
Desiree Carrola, Tom Thornton, Corey Bohil, Kelly Terry

October 29-30, 2014

This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA).

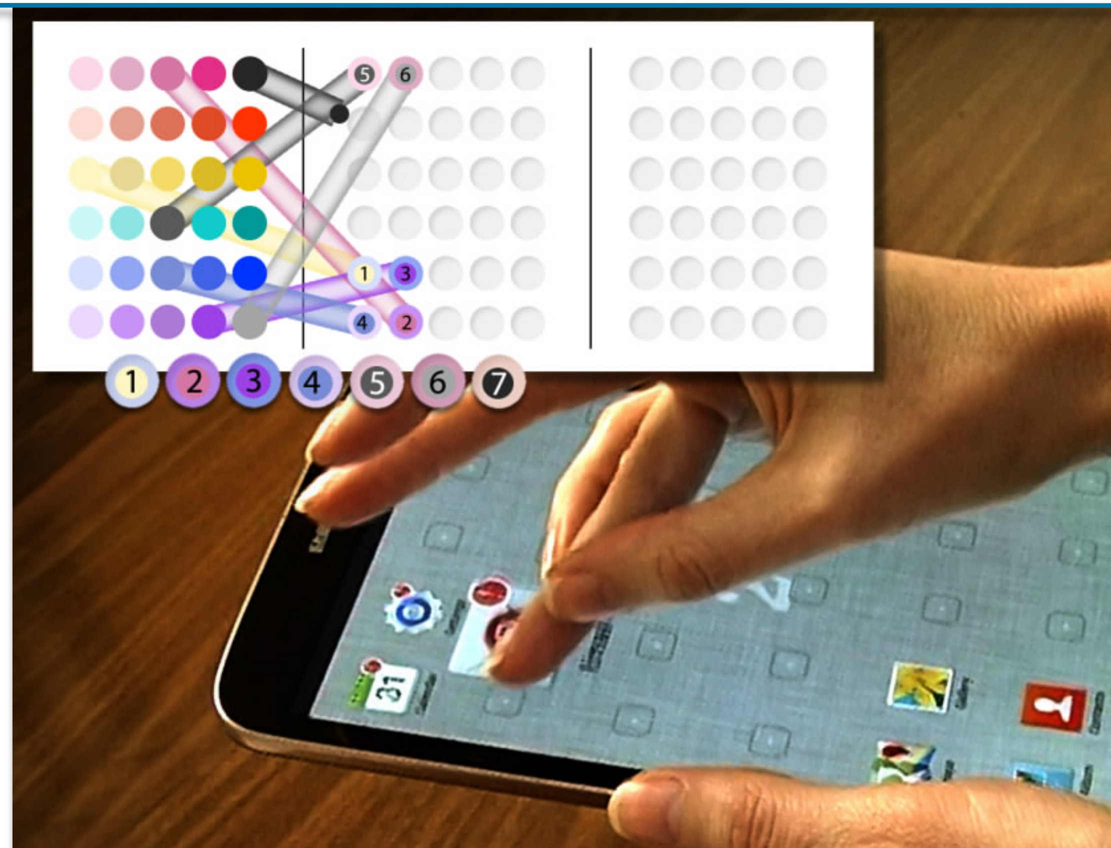
Research Question: Can we design covert games requiring basic reasoning and detect patterns in people's strategies, for authentication technologies?

Users understand software bugs and similar computer issues exist.

Users *consciously* develop resolutions to basic problems, then *unconsciously* incorporate them into their daily routine without interrupting their flow of work.

A covert game was disguised as a customary decision-making mobile device task.

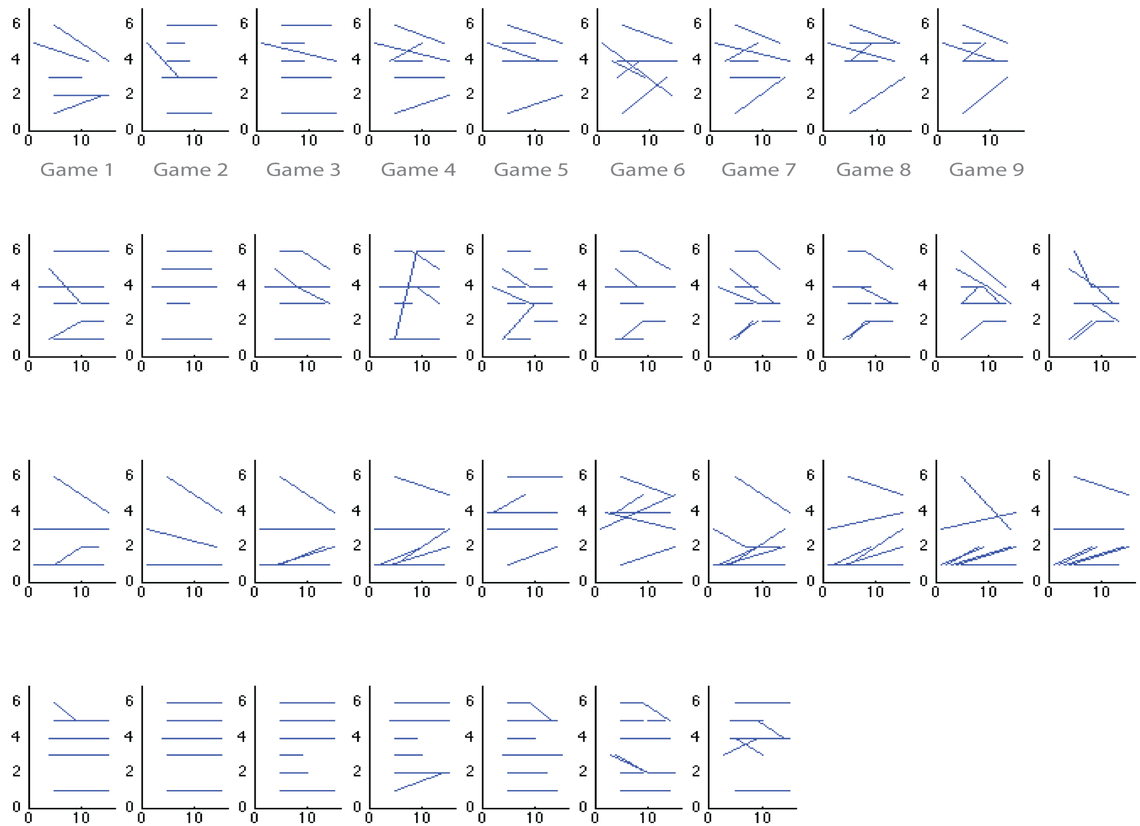
Intermittent ‘updates’ required moving icons in specific ways capturing unconscious and unique decision making strategies.



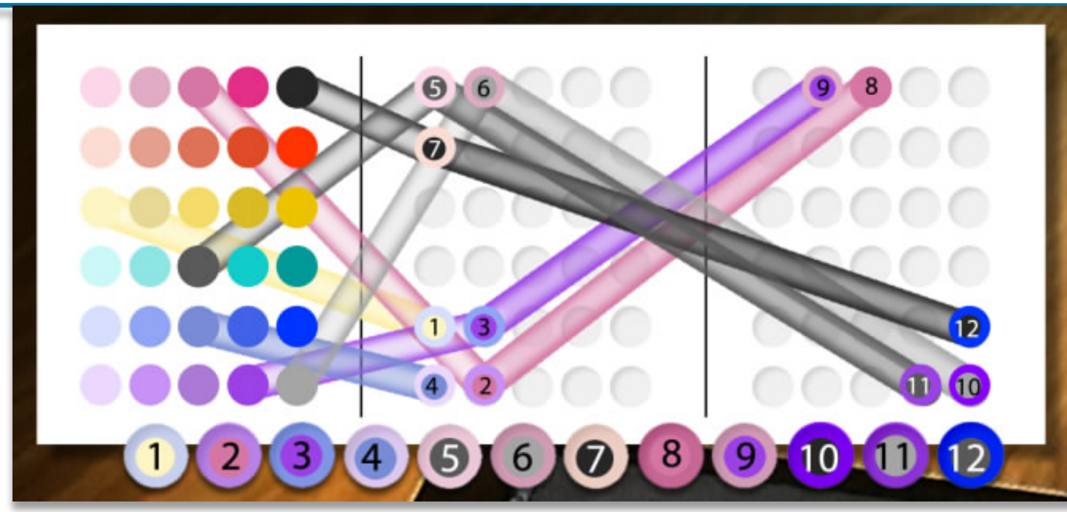
- 3 Pages (device home screens)
- Color indicates row
- 5 puzzle rule variations for moving critical icons
- Numerals show move order
- Shadow streaks depict move distance
- Critical icons are visually identified:

Covert game design framework driven by combinatorial game theory.

A mathematical concept where a series of defined game *piece* '*moves*' achieve a particular ending out of many possible outcomes.

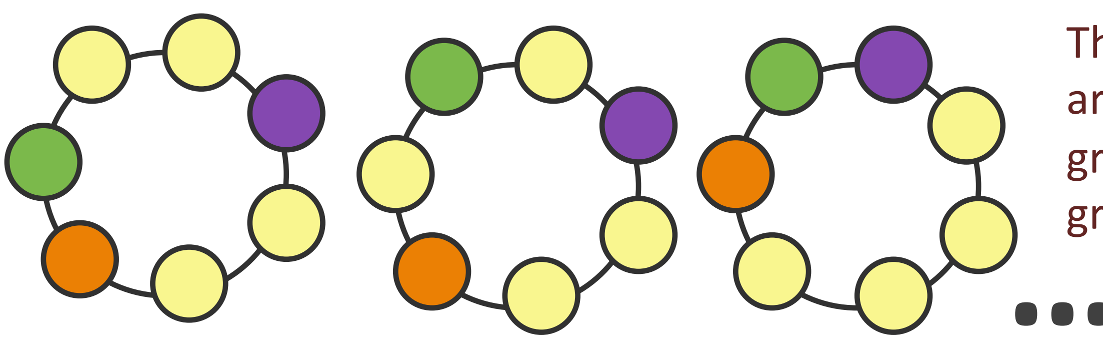


Visualization of data from 4 participants: Covert game-theoretic authentication requires enough variation & permutations for users to engage in.

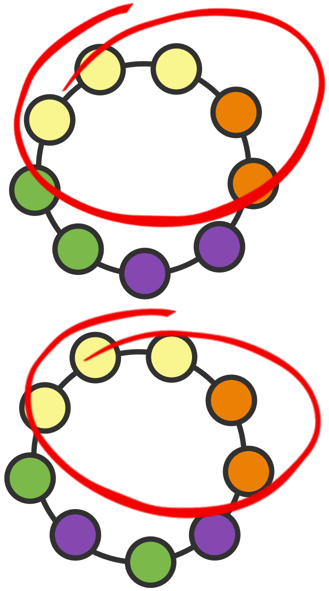


Possible game outcomes are determined by unique ordered sequences of moves or strategies (cognitive fingerprint).

Strategy variations consist of permutations in game piece *choices* (order of operations) & *arrangements* (spatial movements)



The symmetries in the bracelets are analogous to the symmetry groups we identify; order and grouping define game structures.



Strategies form invariant structures within permutation groups, with specific game features such as:

- Moving all non-critical icons first
- Which critical icon element was moved first
- Which row was the first icon moved from

Unique combinatorial structures are classified by an assigned INDEX no.

Each group is characterized by a 'distance' metric, quantifying features from the **SELECT FROM** and **DROP TO** sequences; measure of *movement* (magnitude across game field), *order* and *location* properties

Interval of **non-critical icon** actions and set elements

Interval of **critical icon** actions and set elements

ORANGE: Fixed position Critical Icon 'C'

PURPLE: Random position Critical Icon 'B'

GREEN: Fixed position Critical Icon 'A'

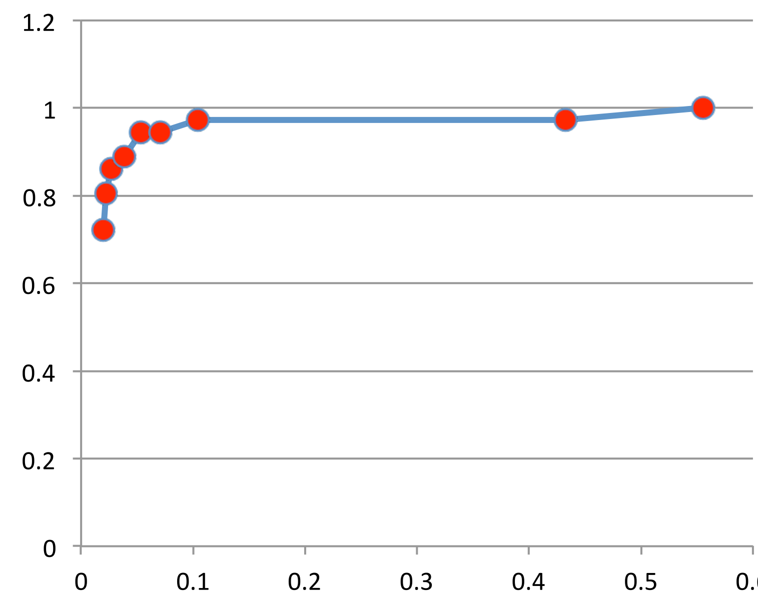
Select From	Drop To	double move
4	5	
10	10	
20	20	4,1 4,1
30	15	5,1 5,1
15	1	3,1 3,1
5	1	
5	2	

Observed that stable game patterns emerged after 6-10 games thus, the last two games were compared.

In the first set of 18 participants we found 14 unique group structures (strategies) with discriminating features, where the current game strategy matches that person's previous strategy.

Users were similar to themselves but different from others

	FAR	HR
0.01	0.0203	0.722222222
0.02	0.0226	0.805555556
0.03	0.0271	0.8611
0.04	0.0384	0.8888
0.05	0.0531	0.944444444
0.075	0.071	0.944444444
0.1	0.104	0.972
0.5	0.4326	0.9722
1	0.5559	1

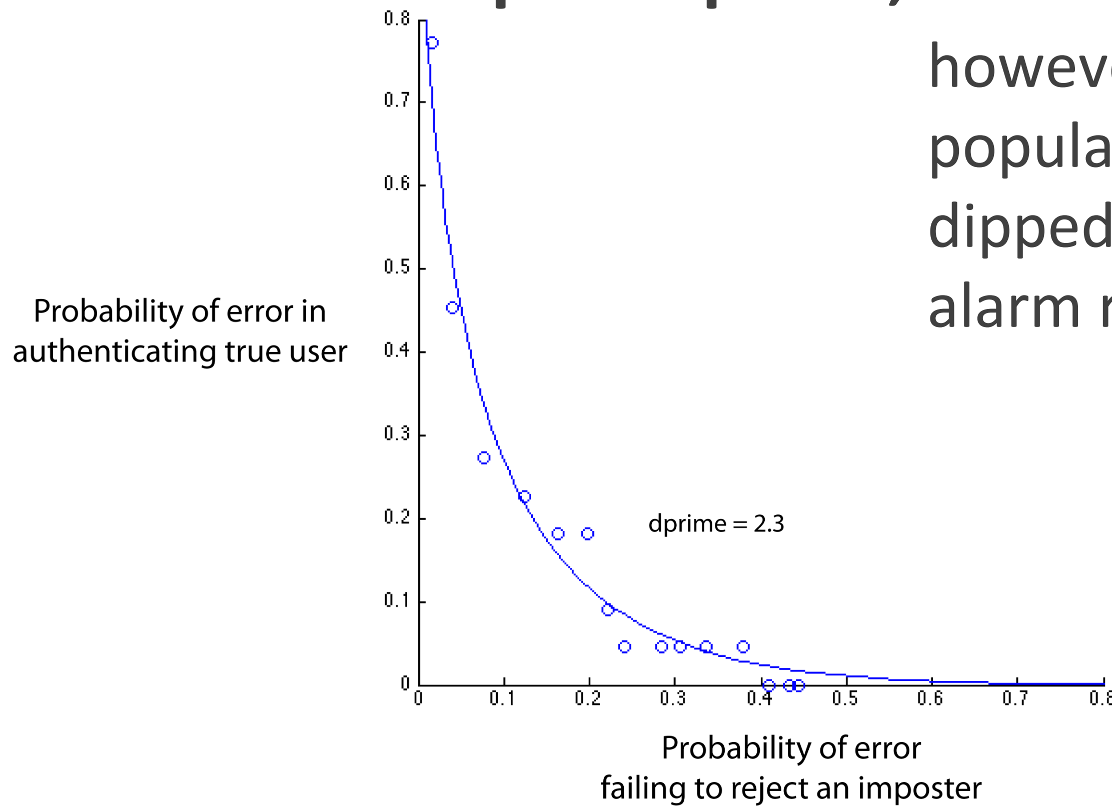


Hit Rate **0.9444**; FRR **0.0531**

These preliminary results were encouraging and provided unique models of individual strategies to a covert combinatorial game.

The next experiment, using a larger sample population, would test whether people continued to form invariant and distinctive gameplay strategies.

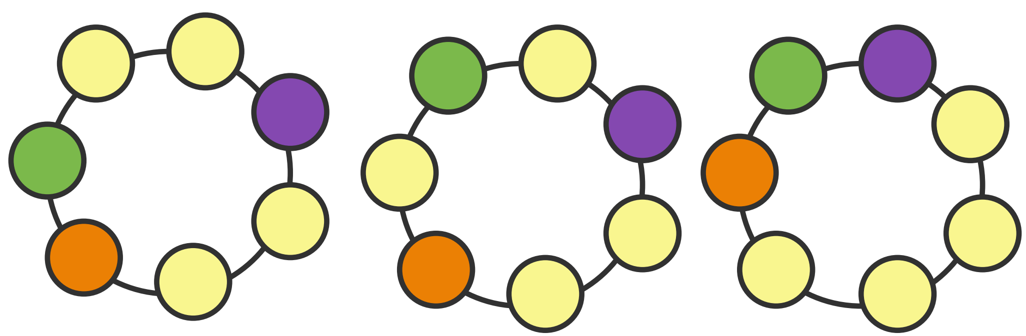
The next test session consisted of 28 participants, the same group-theoretic metrics were used to quantify and discriminate each participant's strategy from those of other participants;



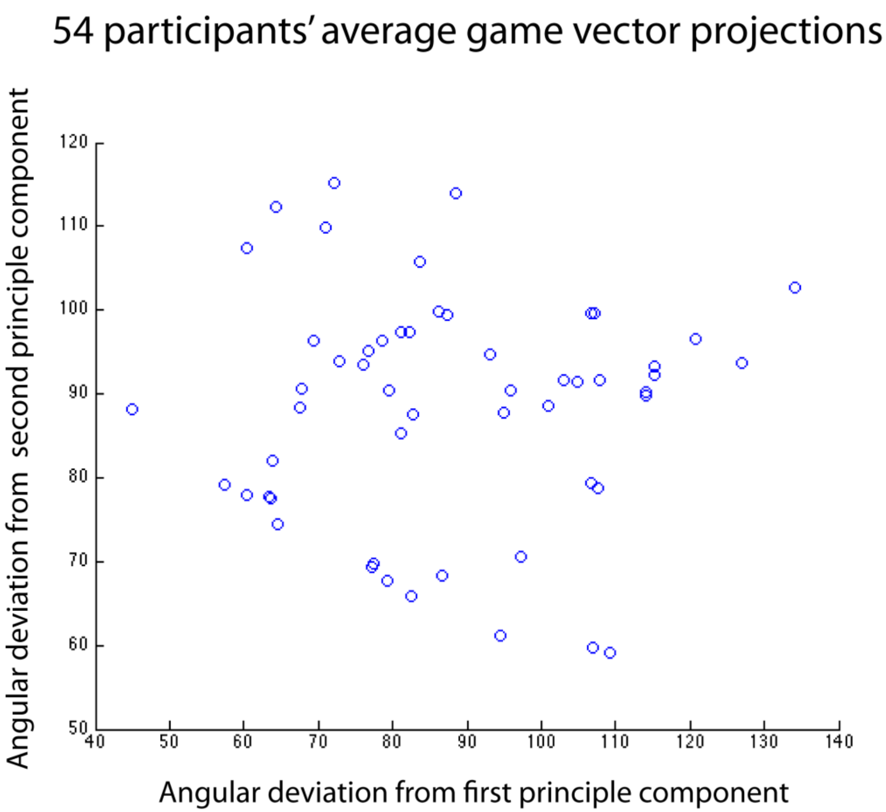
however as the sample population increased, accuracy dipped (~75%) and the false alarm rate increased (~25%)

In this second test session, participants did not exhibit repeatable invariant and distinctive gameplay strategies.

For many, the combinatorial group structures (strategies) differed between games or the group's characteristic 'distance' metric would fluctuate over a wide range of values over the same individual's set of games.



The final test session consisted of 54 participants, during analysis the group structures (strategies) were 'broken up' into 12 characteristic game features.

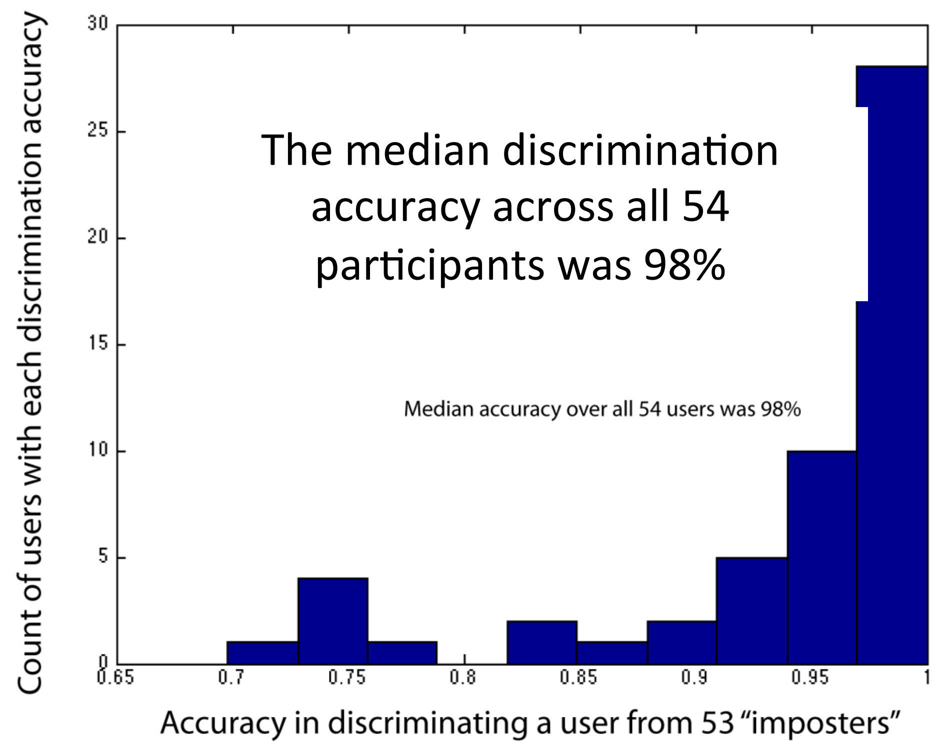


No human observable pattern appeared (well-defined group structure), but cross-ambiguity functions (CAF) and Eigen-analysis quantified and related patterns within gameplay features.

Each dot represents a single participant; disbursed in space they generally do not cluster. Thus qualitatively, the 'fingerprints' are unique and distinguishable from others.

The figure below shows the distribution of discrimination accuracy for each of the 54 participants analyzed.

The distribution is highly skewed to the right indicating that for the vast majority of participants their cognitive 'fingerprint' is highly distinguishable from the 'fingerprints' of all other participants.



The increased error rate appears to be the result of seemingly random gameplay, where no pattern emerged through combinatorial or Eigen-analysis.

Indeed, recent studies have shown that under uncertainty the brain chooses random strategies [Tervo, 2014].

However, research also shows people generally are unable to recognize or produce true randomness [Poundstone, 2014].

Perhaps patterns exist in the 'behavioral noise' within the participants' unconscious strategies?

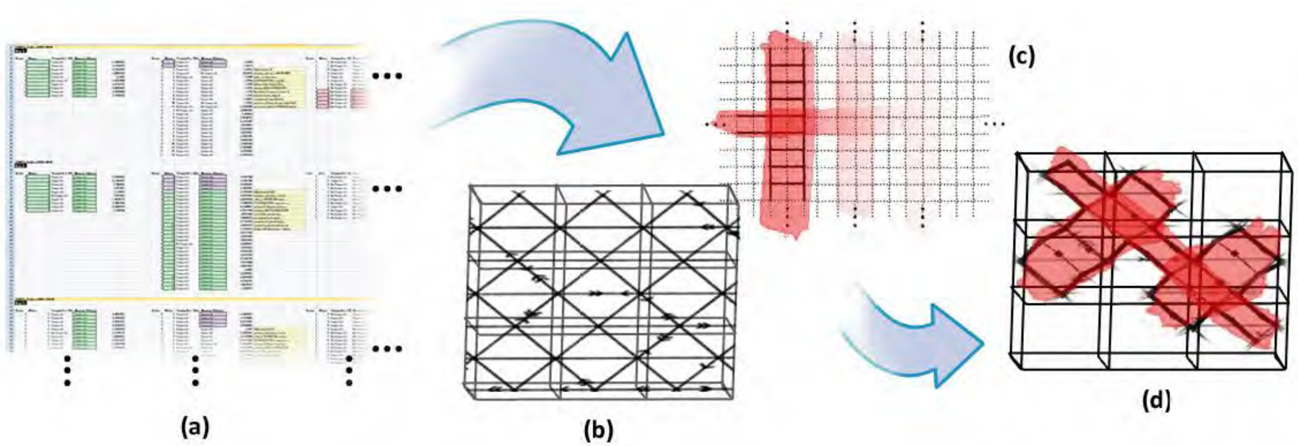
Tervo, Dougal GR, et al. "Behavioral Variability through Stochastic Choice and Its Gating by Anterior Cingulate Cortex." *Cell* 159.1 (2014): 21-32.

Poundstone, William. (2014) *How to Predict the Unpredictable: The Art of Outsmarting Almost Everyone.* Oneworld Publications.

Implementing such behavioral research into the mathematics of combinatorial games, can guide new biometric models of strategies under uncertainty (covert games).

But searching the data for cognitive fingerprints, invariant behavioral features in the combinatorial structures, takes observation and intensive modeling.

However...



Raw gameplay data transformed into topological structures (graphs, groups, etc.) for modeling and classification

Using combinatorial analysis and continuing research into strategy invariants within covert games, we hope to generalize specific combinatorial features.

A set of generalized features would allow this cognitive biometric technique to be embedded into a wider application of covert games or decision-making scenarios; remaining subtle and transparent to the user.

Thanks!

Questions?

SUPPLEMENTARY SLIDES

18

Worked Examples

Select From	Drop To	double move	re-arrange	Select From	Drop To	double move	re-arrange
20	19			19	20		
10	10			20	1		
5	1			14	14		
30	30			5	10		
15	15			15	15	1,5 6,1 1,5	
14	2			**10**	9		
15	15			15	15		
10	10			5	14		
5	1			**10**	10		
30	30			30	25	1,4 1,4	

$$\chi = \sum\left(\left| \text{actions of col. \& rows delta} \right| + \left| \text{average between the SELECTED row \& DROP TO row inputs} \right| \right) + \sum \left| \text{column of averages between the SELECTED row \& DROP TO row} \right|$$

19

Worked Examples (continued)

These two particular examples have a region characteristic of *44*. Both also fall into the symmetric group **pgrp47.**

The resulting ordered pair for both games is :

The resulting ordered pair for both games is :

(44,47)

Magnitude of column movements	Magnitude of row movements	Average between column inputs	Summed total
0	0	2	2
0	4	1	5
0	0	6	6
0	0	2	2
0	4	1	5
0	0	6	6
			26

2	
1	
6	
2	
1	
6	
Sum of Column	18

Summed Total + Summed Column

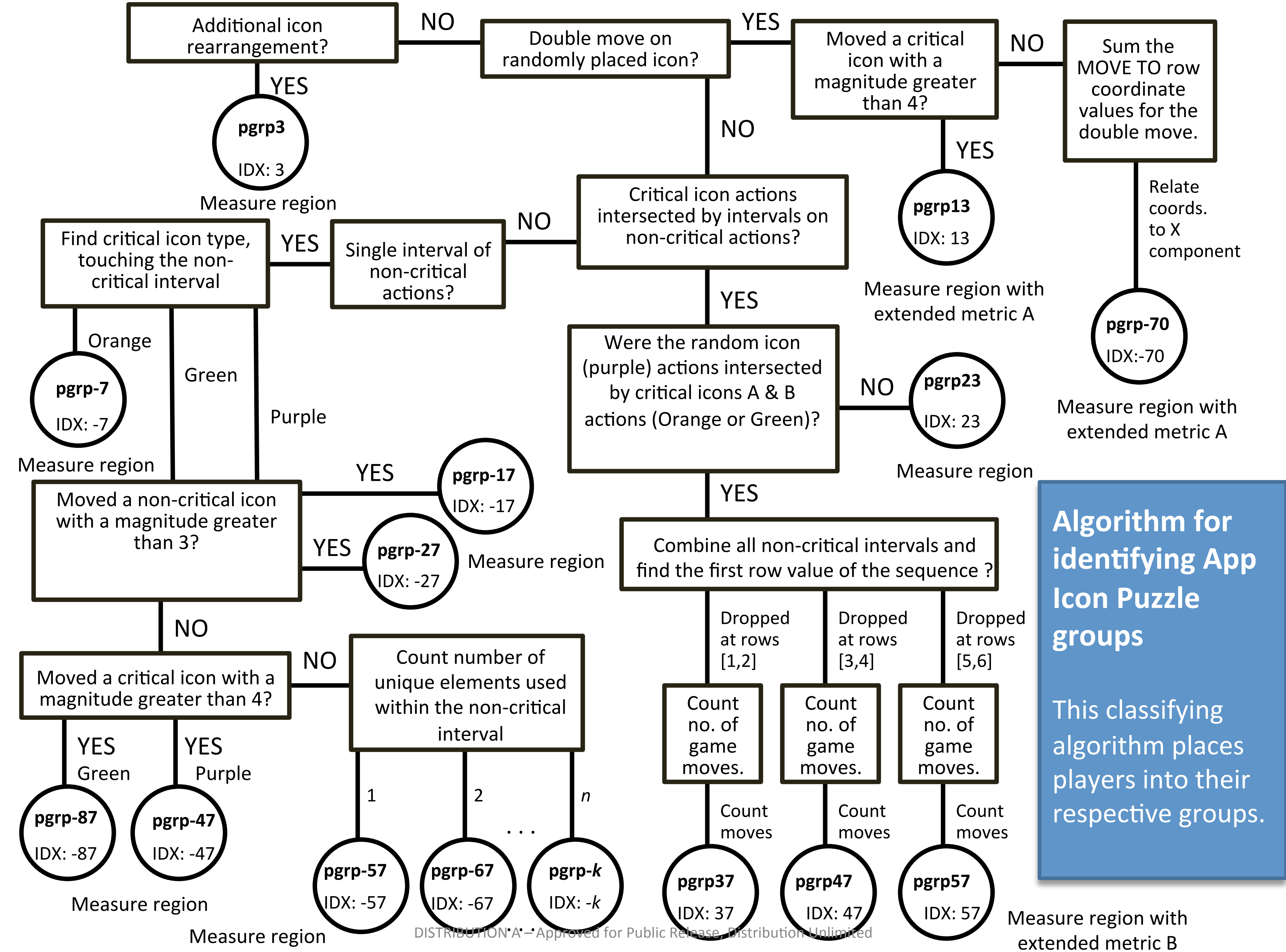
26+18= 44

Magnitude of column movemets	Magnitude of row movemets	Average between column inputs	Summed total
1	0	1.5	2.5
0	1	2	3
2	1	2	5
0	0	2	2
0	0	6	6
0	0	6	6
			24.5

1.5	
2	
2	
2	
6	
6	
Sum of Column	19.5

Summed Total + Summed Column

24.5 + 19.5= 44



Additional icon rearrangement?
NO
YES
pgrp3
IDX: 3
Measure region
Double move on randomly placed icon?
YES
NO
Moved a critical icon with a magnitude greater than 4?
NO
YES
pgrp13
IDX: 13
Measure region with extended metric A
Sum the MOVE TO row coordinate values for the double move.
Relate coords. to X component
pgrp-70
IDX:-70
Measure region with extended metric A
Critical icon actions intersected by intervals on non-critical actions?
NO
Single interval of non-critical actions?
YES
Find critical icon type, touching the non-critical interval
Orange
pgrp-7
IDX: -7
Measure region
Green
Purple
Moved a non-critical icon with a magnitude greater than 3?
YES
pgrp-17
IDX: -17
YES
pgrp-27
IDX: -27
Measure region
NO
Moved a critical icon with a magnitude greater than 4?
YES
Green
pgrp-87
IDX: -87
YES
Purple
pgrp-47
IDX: -47
Measure region
NO
Count number of unique elements used within the non-critical interval
1
2
n
. . .
pgrp-57
IDX: -57
pgrp-67
IDX: -67
pgrp-k
IDX: -k
Measure region
YES
Were the random icon (purple) actions intersected by critical icons A & B actions (Orange or Green)?
NO
pgrp23
IDX: 23
Measure region
YES
Combine all non-critical intervals and find the first row value of the sequence ?
Dropped at rows [1,2]
Dropped at rows [3,4]
Dropped at rows [5,6]
Count no. of game moves.
Count no. of game moves.
Count no. of game moves.
Count moves
Count moves
Count moves
pgrp37
IDX: 37
pgrp47
IDX: 47
pgrp57
IDX: 57
Measure region with extended metric B
Algorithm for identifying App Icon Puzzle groups
This classifying algorithm places players into their respective groups.