# Silent Game

*Understanding Visual and Social Cognition*

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### 9.660 Computational Cognitive Science Final Project

**Abstract**

The vision of this study is to understand human social cognition through graphical communication. In order to study these two aspects of human behavior, we designed an experiment called silent game where two players communicate their goals to each other through graphical interface/board. We documented and tracked the changing beliefs of players of other player's goals based on observation and rational analysis of graphical board at the end of each move. We then designed a computational agent using Bayesian models of inference and documented the inferences developed by that model against the game data collected. The goal of this study was not only to understand human behavior of social cognition and visual cognition, but also test how close can Bayesian computational models get to human-like thinking and intuition development. In short, we wanted to test if *computational models develop an abstract understanding of people's intentions based on visual data?*

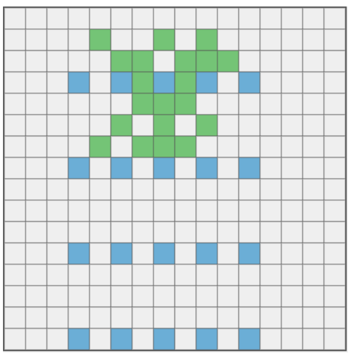


Figure 1: Example of Silent Game board after 4 rounds with intentions Repetition (blue) and Cluster (green)

# 1 Background

This project is based on theories of action understanding and inverse planning[1][2][4] and of visual routines and cognition[5]. The idea of mental states can be distinguished by intentionality which is a characteristic of belief and desires (or goals). In contrast to physical stance of design stance, the intentional stance is the predictive attitude of strategy adopted in order to explain the behavior sufficiently. The theory emphasizes use of intentional strategy as a means to understand intuitive psychology.

# 2 Motivation

This game is inspired by the communication game developed using WebPPL[3] as an example of understanding changes in people's beliefs based on changes in evidence. The game is also based on the assumption that the people behave rationally in order to clearly communicate their intentions to others. Additionally people assume that the observed actions are result of rational and logical thinking. As the evidence accumulates, people form models of other's intentions, motives and behavior by updating their beliefs and changing the confidences in those beliefs.

## 2.1 Social cognition through observation

Developing intuitions of other people's goals and intentions by solely observing their actions is a cognitive behavior in human social interaction. We constantly use this ability of passive inference through observation and lack of linguistic communication in various events like watching sports, dance, mimes and silent movies. Humans also effectively develop intuition of goals and desires of other agents including animals and insects by observing their actions. This ability of attributing mental states to develop an intuition of the world, also commonly known as theory of mind is greatly helpful in fields like anthropology, social science etc. Our goal is to study the theory of mind where in attribution of others' mental states, goals, intents, desires and knowledge is facilitated indirectly through observation of other agent's actions.

## 2.2 Visual routines as tool for observation

While language is the most common and efficient mode of communication and social interaction, we were interested in exploring other non-linguistic modes of understanding other people's goals, intentions and desires. Graphic communication is one such powerful tool of indirect communication wherein images, drawings, photographs, symbols, abstract sketches incorporate meaningful information and concepts. Earliest examples of graphic communication date back to as early as 10,000 B.C. where cave paintings and makings on bones depict communicative representations of ideas, thoughts, intents and collective planning. Use of graphic communication also forms core of various professional fields in design like art, architecture, iconography and design. Visual cognition as an aid for learning is effective deployed in different epistemological settings such as preschools, schools for disabled etc. Being architects and designers, we were interested in deploying the tool of visual cognition as a means of indirect communication between agents. The goal of this experiment was to test how efficiently and effectively can people make inferences of other people's goals by observing graphical representation of their actions.

The practitioners in the fields of design, sciences and engineering depend on the deployment of visual processes that are not specifically object recognition. The term visual cognition includes these processes that are critical to how we reason and make decisions in the world. Shimon Ullman (1996)[5] identified these visual processes as visual routines that can be listed as shifting of processing focus, indexing locations that "pop-out", tracing lines and contours, capturing boundaries, marking particular locations to remember and some others. For example, we are able to decide visually whether an object is inside of some boundary or whether a line has multiple markings on it, relatively fast. Ullman's work is grounded on some key psychophysical studies that recognized that the study of vision is not the study of passive sensory activity but the study a bundle of activities that involve directed attention.

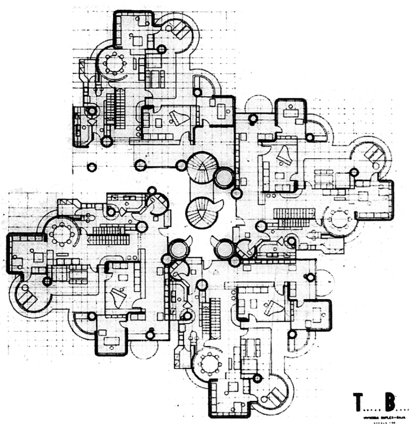


Figure 2: Example of a typical layout in architectural design, designed with concept of clustering

## 3 Silent Game

In order to study the role of two aspects of human cognition – social and visual in our intuitive psychology, we designed an experiment – a silent game. The game is played between two participants with alternating chances to place blocks on a common board. Before the start of the game, each participant is assigned a goal (randomly) that they need to achieve before the game ends. Each player is given 4 chances and the game ends after 4 rounds. After each round of move by one player, the other player is asked to interpret or guess that move and along with the confidence level. The changes in beliefs by both players are tracked by recording them after each move/round. However, in order for the participants to win, the participants need to not only accomplish their own goals, but also ensure that other participant also finishes her task.

Thus, this is a collaborative game – but the players are required to interpret the other person's goal solely by observing their moves on the graphic board. The intent of this game design is multifold – firstly, it motivates each player to clearly communicate their own goals to other player; secondly it incentivizes each player to put in effort to understand each other's intents for effective collaboration for achieving collective goals; thirdly it validates the assumption that the moves played by both players will be rational and aimed to achieve their goals and; fourthly it also reduces the possibility of foul-play, sabotaging, competitiveness or irrational game-play. Furthermore, tracking of the beliefs of players of each other's goals by observing corresponding actions helps in understanding how the inference of actions change with more observed data.

We have selected four visual concepts for our game that necessitate the application of specific visual routines. Some concepts demand the application of same visual routines. We argued that the visual manifestations of each move on the graphic board that are based on the selected concepts will be distinct. At the same time, we wanted to allow for ambiguity in the concepts that could result in misinterpretation of moves. We are excited about the possibility that our game can provide salient insights about the individual visual mechanisms. Looking at the dynamic evolution of the board configuration and confidences can help us the identify regularities among the specific visual concepts and routines employed by each individual. Even the idiosyncratic interpretations provide important information regarding the beliefs of those individuals associated with each concept. Furthermore, visual routines - like testing linearity, scattered coloration etc are used to build the computational Bayesian Inference model.

## 3.1 Instructions

Each game had two randomly chosen players playing remotely without any visual or verbal connection to each other. The players were provided the following instructions before playing the game:

> "This is a collaborative 2 player game. Before the game starts, each payer will be assigned an "intention" - written in green at the top of your web-page. The goal of this game is to: (i) Correctly infer other player's intention and (ii) Effectively communicate your intention to the other player. The mode of communication will be by coloring pixels on a checkered board. We are trying to understand how well people express, communicate, infer and assess other people's intentions and abstract goals by just observation. Each player will have 4 turns to play. In each round, you will be asked to write down your confidence levels of what you believe is other player's intention by entering a numerical value (1-100) in

the boxes provided.

If you are player 1: In your first turn, you just have to draw by coloring the pixels and submit. Turn 2 onwards, you first numerically guess your confidence levels and then play your own intention by coloring pixels.

If you are player 2: You first numerically guess your confidence levels of what the other player's goal might be, and then play your own turn.

*In order to win this game, both players have t successfully guess each others' intention - otherwise both players lose the game.*"

## 3.2 Interface

The link for the game is https://design-game.herokuapp.com. The gameboard consisted of a 16 x 16 pixel grid, which functioned as the drawing board for the players or rather the communication medium for this silent game. In each turn, the player was allowed to fill only 5 pixels in order to communicate their intent. The intention was randomly assigned to each player before the start of the game. The intention was randomly chosen from the set of - (i) cluster, (ii) containment, (iii) intersection or (iv) repetition. The reason for choosing these abstract intentions was to test participant's cognitive understanding of implicit intentions of others. These concepts are derived from the field of design and architecture where designers express their abstract intentions through their designs. Once the first player makes the move, the second player first has to enter their confidence levels (in terms of percentages) in each of the 4 intentions. The following screenshots of the interface explain the process more explicitly.

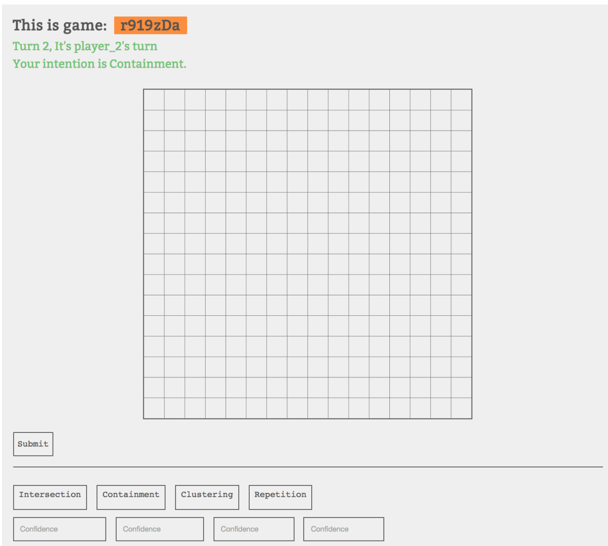



Figure 3: Interface of The Silent Game

## 3.3 Examples

Shown in figure below is an example of a game where player 1's (in blue) intention was *cluster* and player 2's (in green) intention was *intersection*. The figure shows turn wise progress of the game and the chart below shows the change in the confidence levels of opponent's beliefs based on player's actions.

The next example has player 1's intention as repetition and player 2's intention as cluster. These two examples are specifically chosen games - first when both players were unable to guess the other player's intentions and second game was very successful in terms of communication, with high confidence in accurate guesses. The charts shown alongside show the changing confidence levels and beliefs as the game progresses and evidence increases.

In further sections, we compare results and gameboards from different games played and discuss the common concepts used by participants for communicating the intentions.

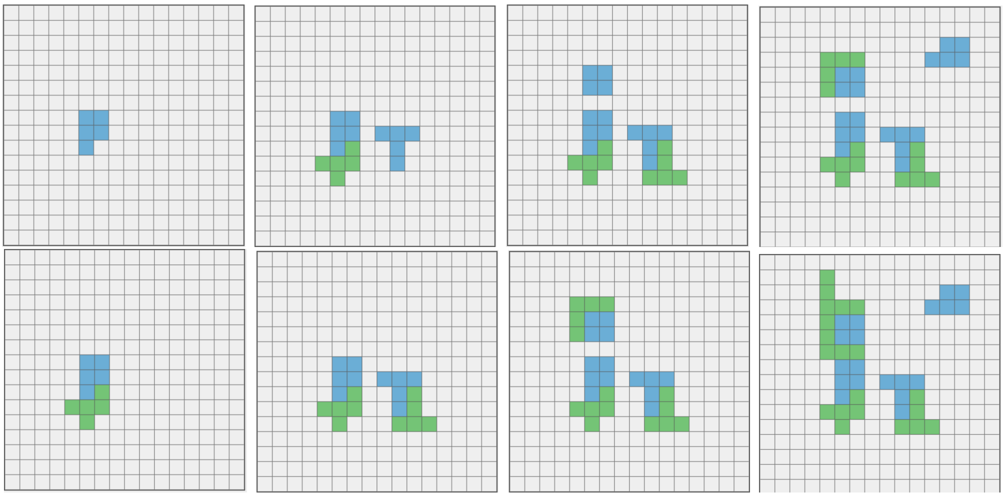


Figure 4: Top row: Moves of player 1 (blue) with intention: cluster and ; bottom row: Moves by player 2 (green) with intention: intersection.

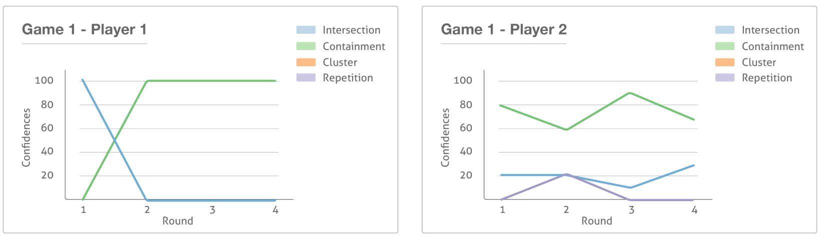



Figure 5: Incorrect Guess Example - left: player 2's confidence levels in player 1's moves; right:player 1's confidence levels in player 2's moves;

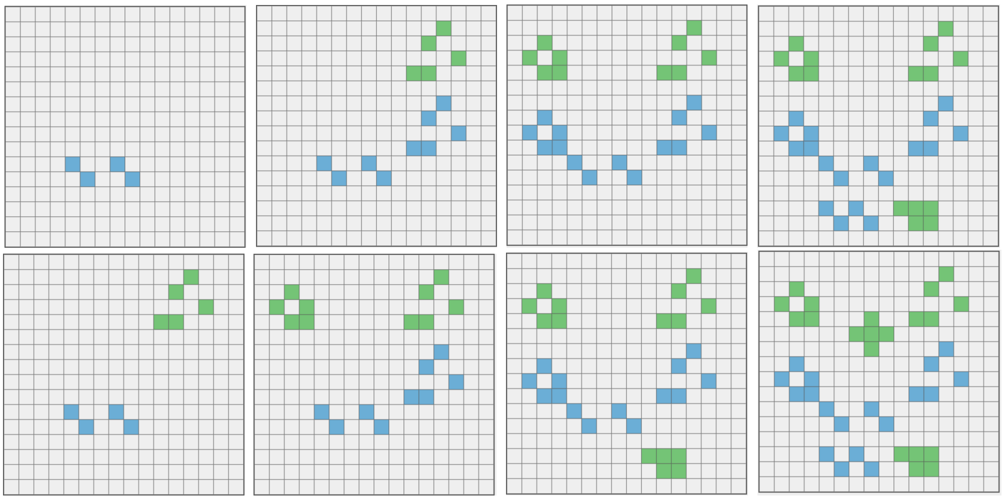


Figure 6: Correct Guess Example - left: player 2's confidence levels in player 1's moves(intention:repetition).

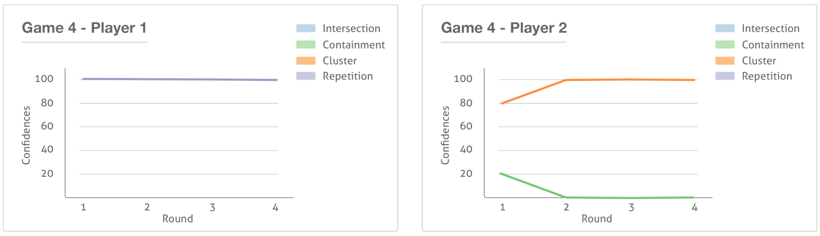



Figure 7: Player 1's confidence levels in player 2's moves(intention:cluster).

# 4 Experiment

The game experiment was conducted 14 times with 14 participants with each player playing the game twice against different participants. Out of 14 participants, 12 were designers and 2 were non-designers. The choice of design-oriented participants was intentional because we wanted to test the commonality in understanding of abstract concepts within the design community of architects. In both the non-designer games, the non-designers were paired with a designer. Interestingly, both the games resulted in miscommunication where non-designers were unable to accurately guess the designer's intention. There was more sync and ease of communication within the intra-designers games. This observation is significant to our hypothesis of testing the common designer vocabulary among the designer community. We believe that this game can be used to further test the differences in understanding of abstract design concepts commonly used by designers especially in designing/planning of layouts - for example symmetry, organic growth, contrast, openness, scale, order, linearity, proportion, hierarchy etc. The next section discusses some specific observations extracted from game play and result analysis.

# 5 Analysis

## 5.1 Observations

- Players who played with the intention: "Cluster" mostly drew 5 pixel together.
- Application of scattered single pixels was another common move for the players who were assigned to "Cluster".

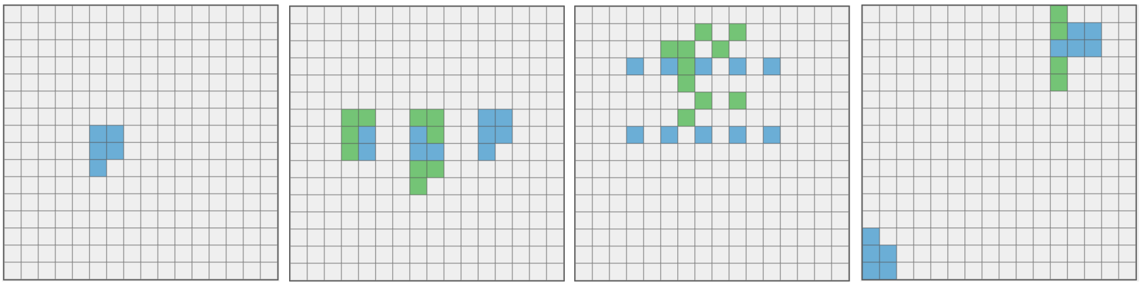


Figure 8: Examples of cluster from Game1(player who plays blue), Game2(both players), Game3(player who plays green) and Game5(player who plays blue

- Intersection involved linear geometries - mostly diagonal

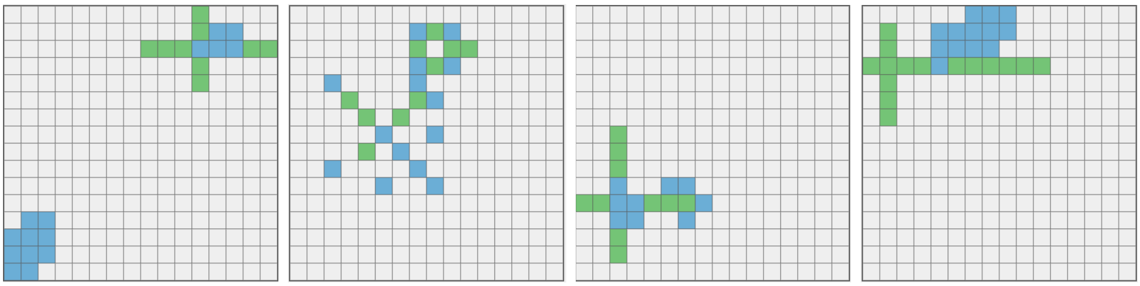


Figure 9: Examples of intersection from Game5, Game8, Game10 and Game12

- In general, participant's belief fluctuate between two options, which means that participants have stronger priors for only two cases and very weak priors for the rest of the options

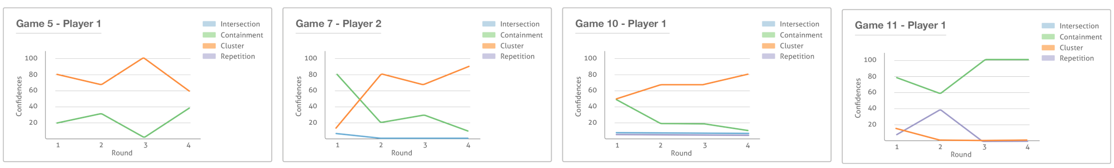



Figure 10: Examples of Player inferences from Game5, Game7, Game10 and Game11

- Repetition was a relatively clearer concept among the participants in comparison to cluster or containment.

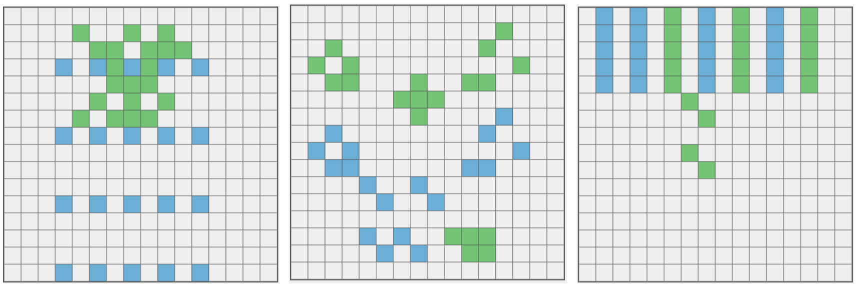


Figure 11: Examples of Repetition from Game3, Game4 and Game6

- "Containment" excited creative strategies as the number of moves that one can play in each turn were limited to 5. One player who were playing with this intention produced boundaries by drawing the pixels on the corners of an invisible boundary. These more territorial strategy turned into a strategy that was aiming to contain the individual pixel or pixels of the other player. In another game, one player used the boundaries of the board to produce an enclosure for a pixel to "contain" it. In the third round, the same player contained an individual pixel of the other player. In the final round, player produced a linear geometry to establish a larger boundary intented to contain the design area.

## 5.2 Inferences

In conclusion, we observed that participants analyzed the game boards by analyzing quantifiable characteristics and relationships between colored pixels. For example - how close the colored pixels, if there was similarity in coloration and position of pixels etc. We further hypothesize that these characteristics can be used to develop a computational model that is capable of using these characteristics and inferring players' intentions and goals.

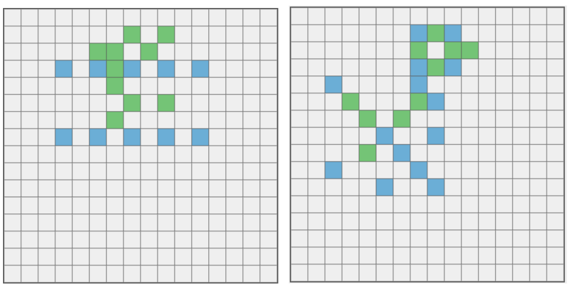


Figure 12: Examples of relation between pixels(similarity,linearity) and intentions(clustering, intersection) in Game3 and Game8

# 6 Computational Model - Bayesian Inference

By analyzing the data from the participants, we could form priors on people's beliefs in certain goals based on characteristics on the game board. The characteristics we extracted were based on analysis of pixels - like if pixels colored are together, or scattered or formed similar pattern. These characteristics can be easily quantified by analyzing the game board graphically and testing pixel coloration.

We modified the communication game and developed a version of Bayesian inference for our Silent Communication Game.

```
var intention = function(pixels) {
  return (pixels == 'Intention_Cluster' ? [0.1, .3, .6] :
          pixels == 'Intention_Repetition' ? [.9, .1, 0] :
          pixels == 'Intention_Intersection' ? [.5, .2, .3] :
          pixels == 'Intention_Containment' ? [.1, .1, .8] :
          'uhoh')
}

var pixelPrior = Categorical({vs: ['similarity', 'scattered', 'together'], ps: [1/3, 1/3, 1/3]})
var intentionPrior = Categorical({vs: ['Intention_Cluster', 'Intention_Repetition','Intention_Intersection', 'Inte
var turn = function(pixels) {return categorical({vs: ['similarity', 'scattered', 'together'], ps: intention(pixels

var Player_1 = function(pixels, depth) {
  return Infer({method: 'enumerate'}, function() {
    var draw = sample(pixelPrior);
    condition(sample(Player_2(draw, depth)) == pixels)
    return draw
  })
}

var Player_2 = function(draw, depth) {
  return Infer({method: 'enumerate'}, function() {
    var pixels = sample(intentionPrior);
    condition(depth == 0 ?
              draw == turn(pixels) :
              draw == sample(Player_1(pixels, depth - 1)))
    return pixels
  })
}

viz.auto(Player_2('scattered', 3))
viz.auto(Player_2('similarity', 3))
```

run

Figure 13: WebPPL code for computational model of Bayesian Inference

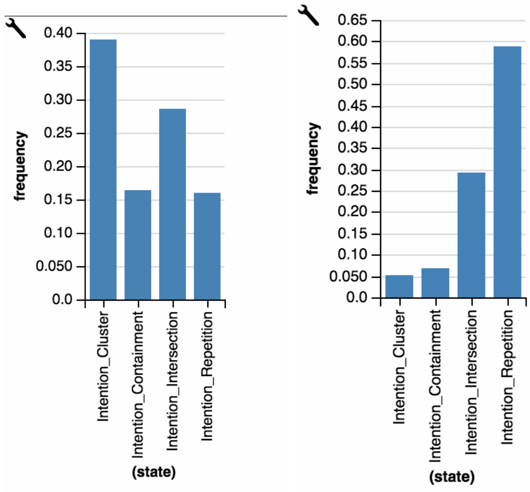



Figure 14: WebPPL visualization for computational model of Bayesian Inference

# 7 Further Research

- This game can include some common cognitive intuitive psychology concepts involved in games like chess, go etc like defensive play, aggressive play etc.
- The game can be made more collaborative by eliminating difference of colors and allowing the players to build commonly on the game-board. This aspect would then require the players to further communicate effectively.
- The game can be adapted to include changing intentions in every move and track how every individual plays and guesses each of the different intentions
- A computational prediction Bayesian model can be developed from this data. By training the model on people's confidence levels, we can extract general priors of people's intuition/beliefs of various visual blocks and connected concepts
- With enough data, we can reverse engineer intuitive psychology as the model can start reading the board and making accurate guesses and confidence in other player's intentions
- We observed that some dynamics of the game could be modeled with Hidden Markov Models. In half of the games, initial confidence values provided by the players influenced the values in the later rounds. For example, when some move is interpreted as "Containment" and when there is also a more likely candidate, even if its confidence values showed a decreasing trend, that intention was still considered to be a candidate. However, as the history of the game is available at each round, in four games, re-structuring enabled players to introduce the third likely candidate as the most likely in later rounds. One interesting observation about these cases is that in three out of four games, players spared a small confidence value to that candidate in the initial round.

- We formed an intuitive understanding of the common strategies for each intention. We hypothesize that all of these strategies are identifiable through the application of visual routines and processes. In order to translate these strategies into likelihoods we could use the strategy that is used by Griffiths and Tenenbaum (2007). It is possible to construct mixture models with specific combinations of Uniform and Gaussian distributions. For example, one common player strategy for intersection was intersecting a other player's geometries with linear geometries. Likelihood for this strategy can be computed by looking for the best fit among the family models that is based on the interaction of multiple multivariate Gaussians.
- The game can be used to further test some commonly used abstract concepts in design and architectural field like symmetry, organic growth, contrast, openness, scale, order, linearity, proportion, hierarchy etc.

## 8 Contributions

- Designed an experiment that brings together concepts of human visual cognition and social cognition in one experiment
- Tested people's intuition on other people's actions using the silent game experiment
- Designed a computational model capable of deciphering abstract visual concepts by training on human data
- Demonstrated how a Bayesian model would use the relationships between the colored pixels to infer player's goals
- Analyzed the results to extract the differences between abstract interpretations of design concepts between designers and non-designers

## References


[1] Zalta, E. N., and Dennett D. (1989) *The Intentional Stance.* 397-400. Cambridge MA: Bradford Book.

[2] Baker, C. L., Rebecca S., and Tenenbaum, J B.,(2009) "Action understanding as inverse planning." *Cognition 113*, 329-349.

[3] Griffiths, T. L., Tenenbaum, J. B. (2007) From mere coincidences to meaningful discoveries, *Cognition 103*, 180-226.

[4] The communication game: https://probmods.org/v2/chapters/06-inference-about-inference.html

[5] Shafto, P., Goodman N. D. , and Frank, M. C. (2012) Learning from others the consequences of psychological reasoning for human learning. *Perspectives on Psychological Science, 7.* 341-351.

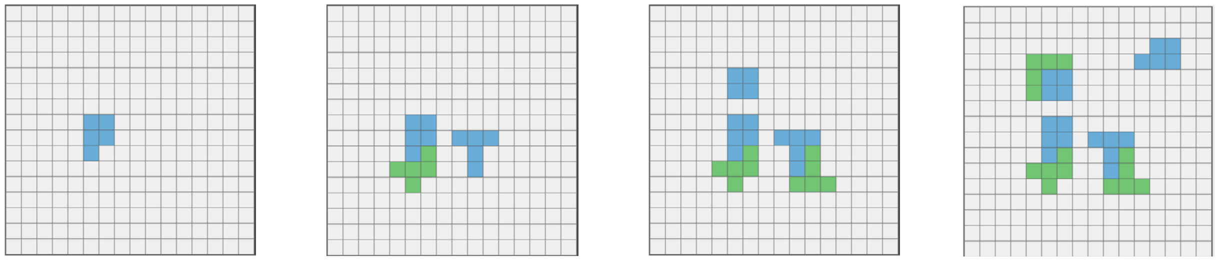
[6] Ullman, S. (1996) Visual Cognition and Visual Routines" in *High Level Vision.* Cambridge MA: MIT Press.

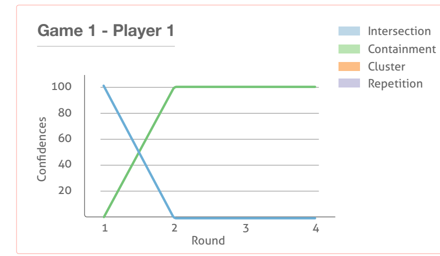
[7] The Silent Game link: https://design-game.herokuapp.com ; Access to the code: https://github.mit.edu/egeozin/Design-Game .

# 9 Appendix

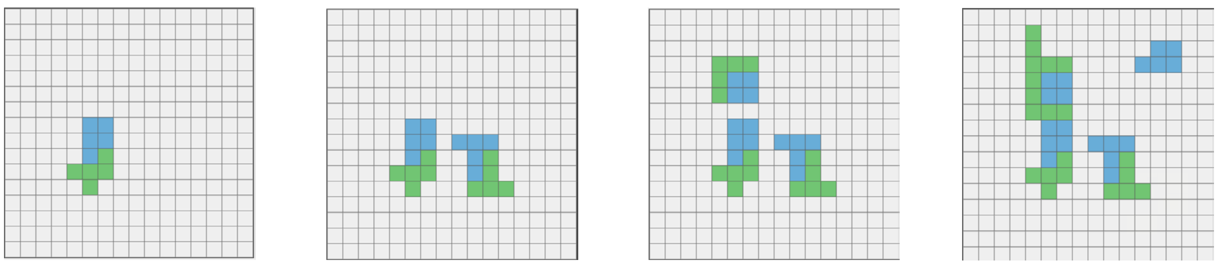
Check the data from the fourteen games in the following pages. Plots corresponding to each player shows the interpretations of the other player about that player.

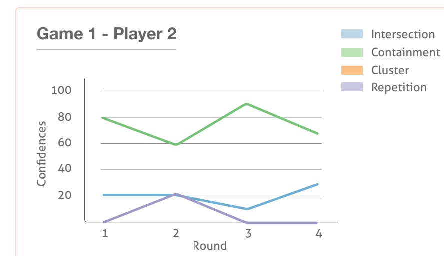
## Game 1 - Player 1 - Cluster



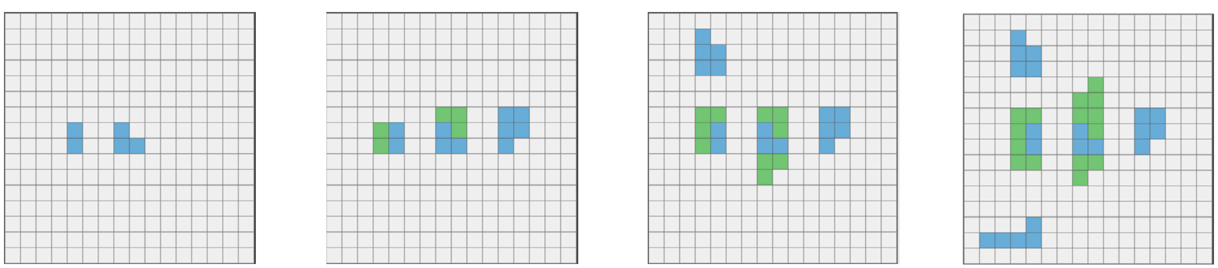


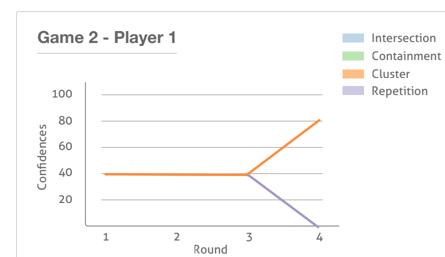

## Game 1 - Player 2 - Intersection



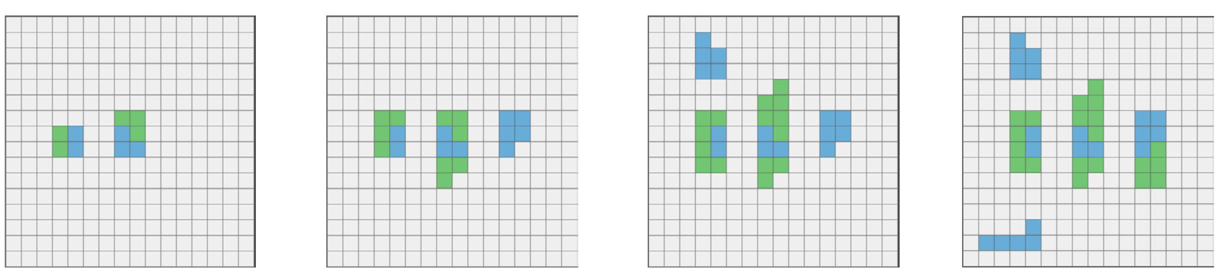


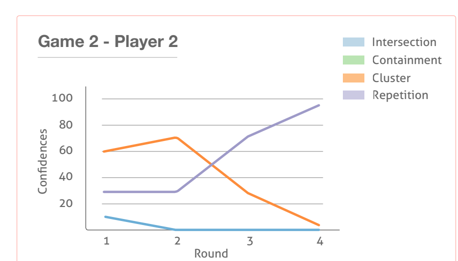

## Game 2 - Player 1 - Cluster



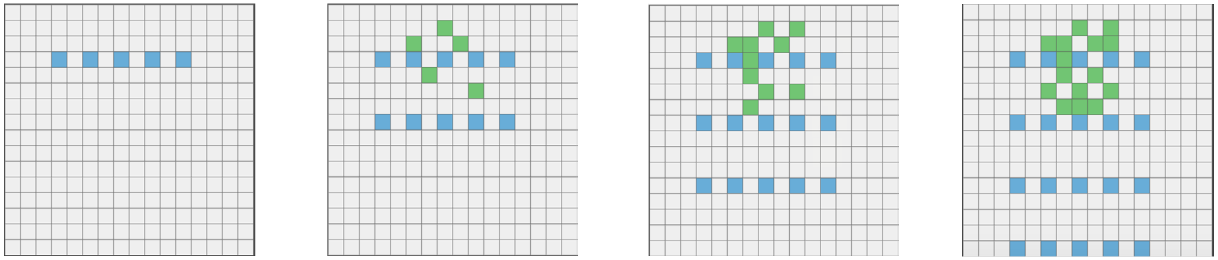


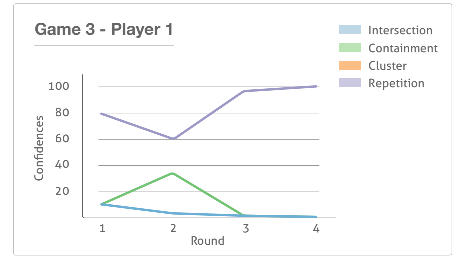

## Game 2 - Player 2 - Cluster



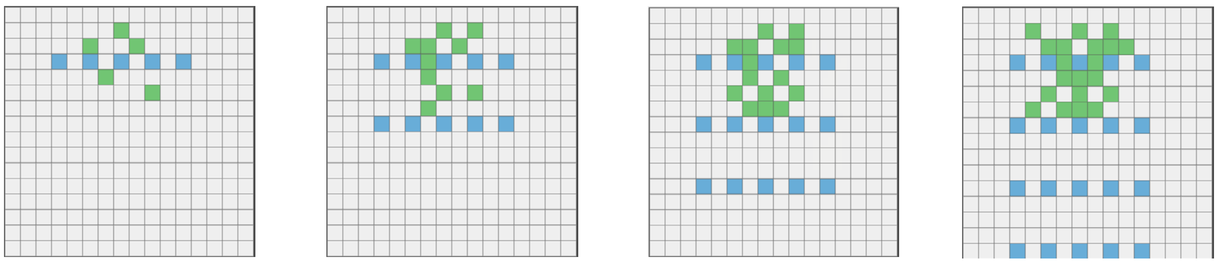


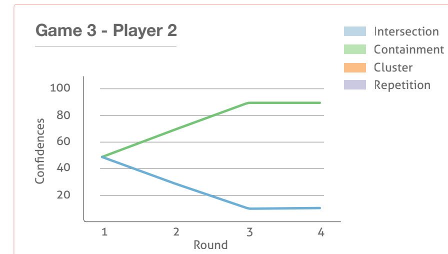
## Game 3 - Player 1 - Repetition






## Game 3 - Player 2 - Cluster



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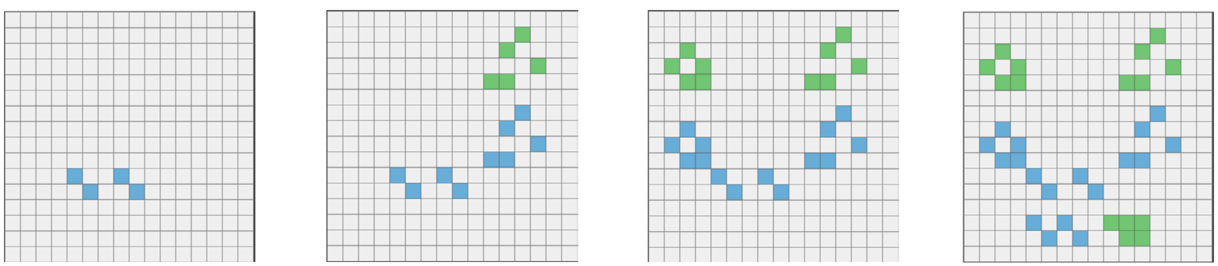
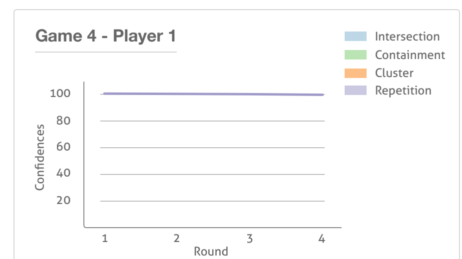
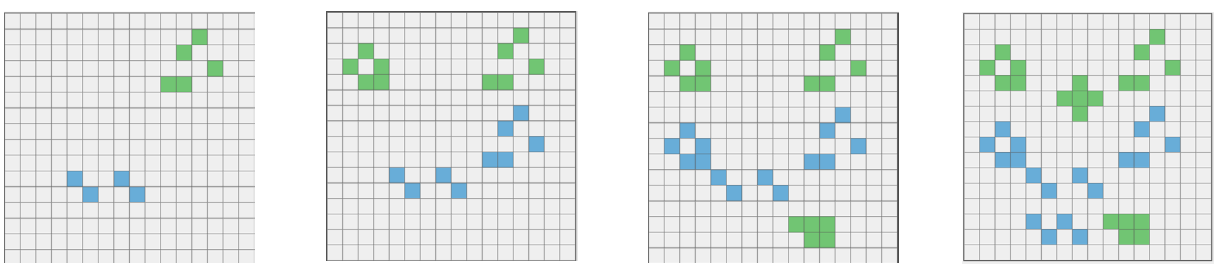
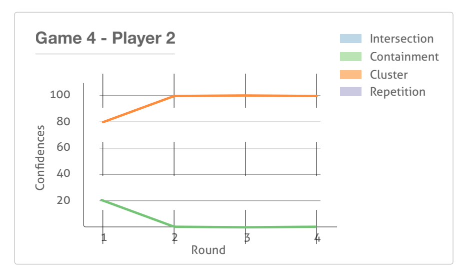
## Game 4 - Player 1 - Repetition



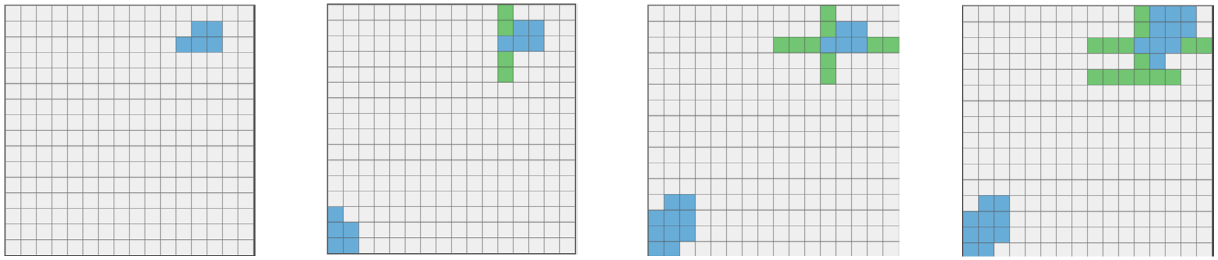


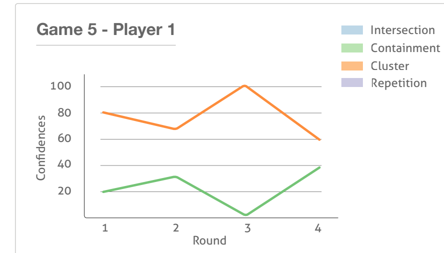

## Game 4 - Player 2 - Cluster



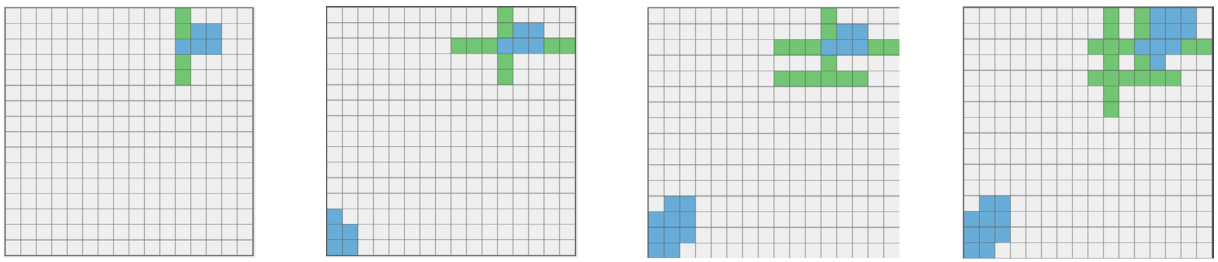


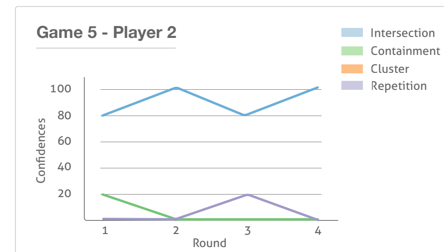
# Game 5 - Player 1 - Cluster



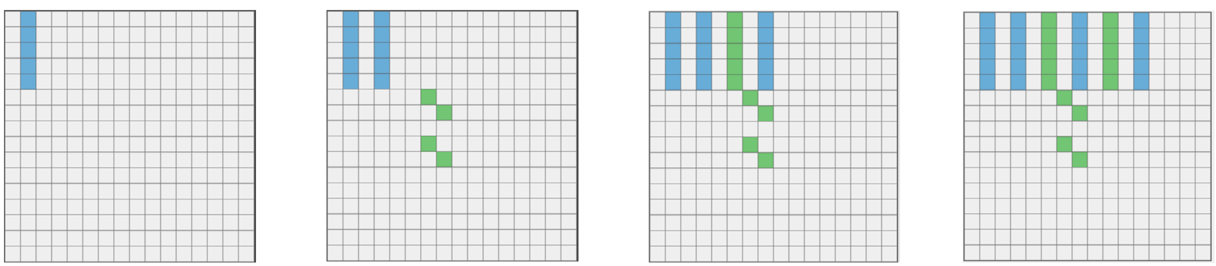


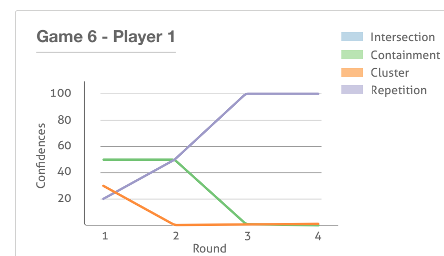

# Game 5 - Player 2 - Intersection



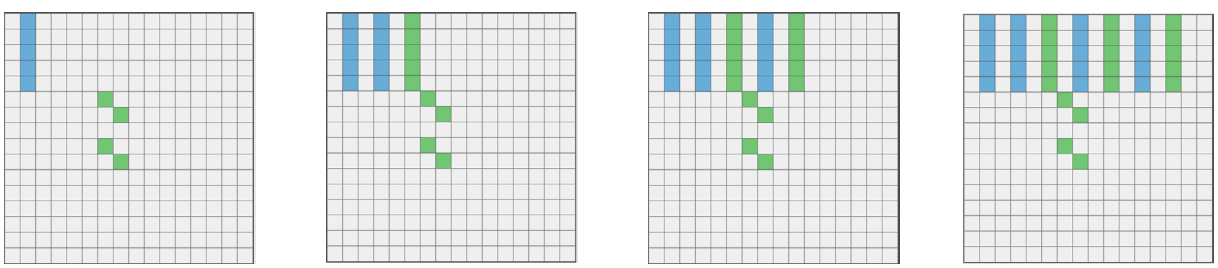


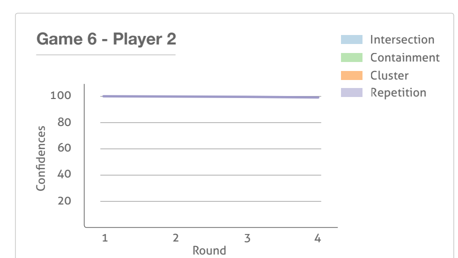

# Game 6 - Player 1 - Repetition



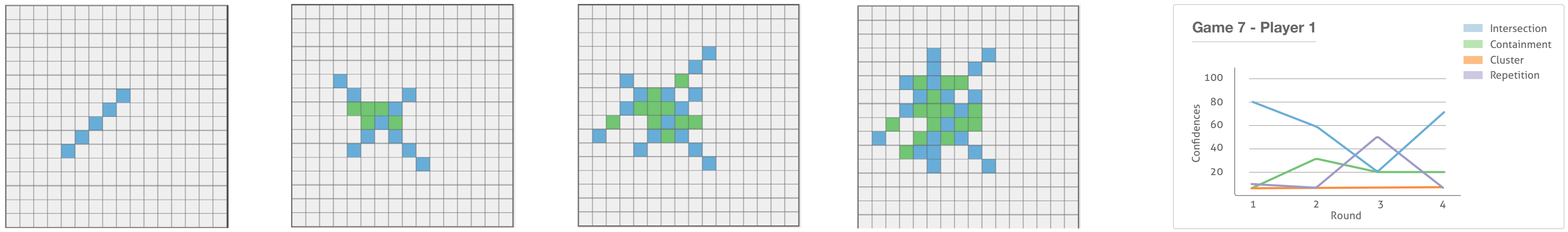



# Game 6 - Player 2 - Repetition

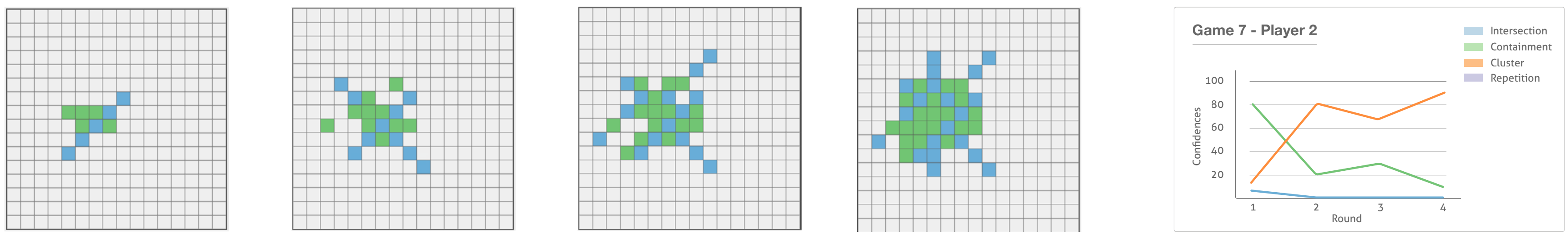




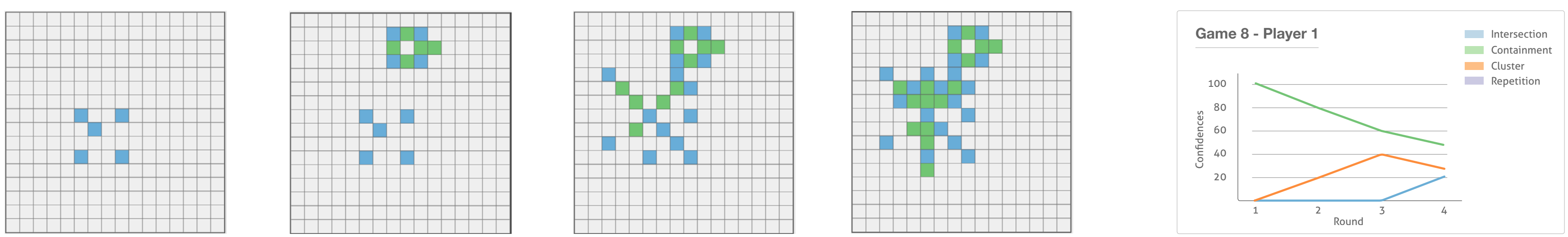
# Game 7 - Player 1 - Intersection




# Game 7 - Player 2 - Cluster




# Game 8 - Player 1 - Containment




# Game 8 - Player 2 - Intersection