Rational Dialog in Interactive Games

Maria Arinbjarnar

Thesis Advisor Luca Aceto
Department of Computer Science
Reykjavik University

May 2007
Why Make NPCs Rational?

- Role-Play games & Adventure games
- Rigid and scripted story lines
- Simple NPCs, they always react the same and in a very limited way.
**Proof of Concept**

**Research Question**

Will an NPC interact with a player and other NPCs in a rational and goal driven way, when given a past life and a decision mechanism?

My focus is on interactive dialog and I built an engine that uses:

- Propps Morphology and Bayesian networks to generate a past life and connections with other payers.
- Bayesian networks as a causally connected decision mechanism.
- Game Theory as a means to calculate a rational strategy.
- Tools: GeNIe & SMILE, Java, Intellij.
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RATIONALITY

DEFINITION

Rationality is the choice of actions which best satisfy a person’s objectives. These objectives are desires that motivate the individual.

Objectives or desires include for instance:

- Satisfying feelings.
- Morals, integrity, being liked.
- Being successful, discovering and advancing in some area.
- Avoiding trouble, hiding uncomfortable truths.
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The Fool’s Rationality

- A fool in a marked place is surrounded by a small crowd that repeatedly asks the fool to choose between a pound and a half pound.
- The fool always picks the half pound over a pound.
- "Well, how long would they play this game if I picked the pound?"
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RATIONALITY IN GAME THEORY

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A Nash equilibrium is a profile of strategies such that each player’s strategy is an optimal response for each of the other players’ strategies.

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- No other strategy profile will yield a higher payoff.
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$$u_i(\sigma_i^*, \sigma_{-i}^*) \geq u_i(s_i, \sigma_{-i}^*)$$

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Nash equilibrium deals with complete information games.

A dialog is not a complete information game.


In a three-part paper published in 1967 and 1968, shows how to convert a game with incomplete information into one with complete yet imperfect information, so as to make it accessible to game-theoretic analysis.
Incomplete Information Games

- Nash equilibrium deals with complete information games.
- A dialog is not a complete information game.
- In a three-part paper published in 1967 and 1968, shows how to convert a game with incomplete information into one with complete yet imperfect information, so as to make it accessible to game-theoretic analysis.
The result of Harsanyi work is **Bayesian equilibrium**. Probabilities are used to convert incomplete information into imperfect information. I will discuss the Bayesian equilibrium in conjunction with the part of the engine that calculates equilibrium. First it is good to understand the basics of the engines setup.
**The Big Picture**

- Bayesian net
- Generate plot
- Proppian functions
- Generate NPC decision mechanism
- Vectors for feelings, goals etc.
- Game Theory
- Plot
- NPC 1
- NPC 2
- NPC 3

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The Dynamic Plot Generating Engine

- The engine uses a Bayesian network to generate a new murder mystery plot for each new game initialized.
- The resulting plot is a consistent murder mystery that is solvable with logical inference.
- It contains:
  - One and only one murderer and murder weapon.
  - On victim and a murder scene.
  - Other suspects and weapons
  - Possible motives for the murderer and other suspects
Vladimir Propp, a Russian structuralist, (St Petersburg, April 29, 1895 - Leningrad August 22, 1970)

1. Functions of characters serve as stable, constant elements in a tale, independent of how and by whom they are fulfilled. They constitute the fundamental components of a tale.

2. The number of functions known to a fairy tale is limited.

3. The sequence of functions is always identical.

4. All fairy tales are of one type in regard to their structure.
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Generating a Plot

1. Read text files that describe the initial net.
2. Draw the initial net based on the settings
3. Initiate a victim
4. Initiate a murderer
5. Initiate a murder weapon
6. Eliminate all other suspects as possible murderers
7. Eliminate all other weapon as possible murder weapons
8. Instantiate the rest of the network
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Motives

- Swindle
- Blackmail
- Wedlock
- Inheritance
- Adultery
- Revenge
- Dept
Each NPC is generated from the plot that the DPGE generated. This means each suspect and the murderer are generated as an independent NPC. Complete with:

- Characteristics.
- Connections between characters.
- Connections between victim and characters.
- Motives and evidence.
# The NPC Knowledge Base

## Character
Characteristics, crime knowledge, weapon knowledge, scene knowledge

## Characters Opponent
Characteristics, crime knowledge, weapon knowledge, scene knowledge

## Characters Opponent Opponent
Characteristics, crime knowledge, weapon knowledge, scene knowledge
<table>
<thead>
<tr>
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THE NPC KNOWLEDGE BASE

- Mother Inf
  - Rosamund 19%
  - Alice 55%
  - Null 26%

- Mother Prem
  - Rosamund 29%
  - Alice 29%
  - Null 42%

- Hearsay
  - Rosamund 10%
  - Alice 81%
  - Null 10%

- Alice value
  - Rosamund 10%
  - Alice 81%
  - Null 10%

- Alice hearsay
  - Rosamund 0%
  - Alice 100%
  - Null 0%
The sentences are generated from the knowledge variables.

Each knowledge variable can be stated as true or false.

A sentence is created from one or more knowledges.
Generating sentences

Harry_Reply_Knowl...
- Poison: 0%
- Spanner: 100%
- Club: 0%
- Knife: 0%

Contradiction
- True: 75%
- False: 25%

Risk
- True: 0%
- False: 100%

Main contradiction
- True: 75%
- False: 25%

Main risk
- True: 0%
- False: 100%

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In order to find equilibrium we need a mathematical definition.

Harsanyi proposed to use types to represent different states that the opponent could be in.

Types Θ are really all possible positions that the Bayesian net could be in at a given time.

Essentially a cross product of all the variables in the net.

Still it is possible to reduce the problem to a finite set of types of a manageable size.
DEFINITION

Given a strategy profile \( s(\cdot) \), and an \( s'_i(\cdot) \in S^\Theta_i \), let \((s'_i(\cdot), s_{-i}(\cdot))\) denote the profile where player \( i \) plays \( s'_i(\cdot) \) and the other players, his opponents, play \( s(\cdot) \), we let

\[
(s'_i(\theta_i), s_{-i}(\theta_{-i})) = (s_1(\theta_1), \ldots, s_{i-1}(\theta_{i-1}), s'_i(\theta_i), s_{i+1}(\theta_{i+1}), \ldots, s_i(\theta_i))
\]
The probability of an opponent being of any given type $p_{-i}(\theta_{-i})$ is strictly positive.

We use prior calculations to find the probability that the opponent is of a given type $p_{-i}(\theta_{-i})$.

We use prior calculations to find the opponent’s strategy for each of his possible types $s_{-i}(\theta_{-i})$. 

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**Bayesian Equilibrium**

**Definition**

We find an equilibrium by maximizing the sum of player $i$ weighted payoff $u_i$, conditional to his type $\theta_i$, over the opponents’ possible types $\theta_{-i}$, for each of his strategies $s'_i \in S_i$ as is shown here:

$$s_i(\theta_i) \in \arg \max_{s'_i \in S_i} \sum_{\theta_{-i}} p(\theta_{-i}|\theta_i)u_i(s'_i, s_{-i}(\theta_{-i}), (\theta_i, \theta_{-i}))$$
(Fudenberg & Tirole 1991)

- Since Bayesian equilibrium, like Nash equilibrium, is essentially a consistency check, players’ beliefs about opponents’ beliefs do not enter the definition.
- All that matters is each player’s own beliefs about the distribution of types and his opponents’ type-contingent strategies.
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- All that matters is each player’s own beliefs about the distribution of types and his opponents’ type-contingent strategies.
Koller and Milch, Stanford University, propose a very good way to tackle the same problem as discussed, namely dealing with the incomplete information of every day decision making.

Their solution is a Multi-Agent Influence Diagram (MAID).

A MAID is an expanded Bayesian net in order to calculate Nash equilibrium.

The MAIDs structure divides the decision process up in as many nets as there are decisions to make and then each decision is made in a reverse topological order.
In a dialog there are two decisions, the sentence and the reply.

The next step then is to find all the set of optimal replies for each of the sentences using the Bayesian net.

There are complexity problems due to too many entries in the decision variables.

It is not possible to just split the decision variables.

If there are 9 other variables, each having 10 states, that need to be evaluated, then the strategy function of each decision variable has a complexity of $10^9$. 
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If there are 9 other variables, each having 10 states, that need to be evaluated, then the strategy function of each decision variable has a complexity of $10^9$. 
Each decision variable needs to be calculated separately. This means that the sentence and speech part of the net needs to be recreated for each set of sentences and for each set of replies calculated.

First optimal replies to each of the sentences are found. Then a set of optimal sentences is found in respect to the optimal replies.
Rosamund says: Horace did not hold me in wedlock.

Alice says: Horace did not hold me in wedlock.

Rosamund says: I’m not Horace’s wife.

Alice says: I’m not Horace’s wife.

Rosamund says: I’m Horace’s parent.

Alice says: Horace did not have an affair with a male.

Rosamund says: I’m Horace’s mother.

Alice says: Horace was having an affair with me.

Rosamund can’t think of anything to say!
RESULTS

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CONCLUSION

- The concept is proved.
- Even without many possible optimizations the time needed to calculate more than 75% of the sentence is within 3 minutes and more than half of the sentences are calculated in less than 1 minute.
- Linear growth in respect to number of sentences.
- Players are able to adapt to what they hear from their opponents.
- This approach uses calculations and logic to infer what action to choose.
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**Future Work**

- Maturing the DPGE (Dynamic Plot Generating Engine).
- Maturing the player’s decision mechanism.
- Generating sentences in a more logical and way.
- Optimizing calculations.
- Use Natural Language Processing for a more speech-like sentence generation.
- Courtesy mode.
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