

"Every creative act is open war against The Way It Is. What you are saying when you make something is that the universe is not sufficient, and **what it really needs is more you**. And it does, actually; it does. Go look outside. **You can't tell me that we are done making the world.**"

-Tycho Brahe, Penny Arcade

- “Everything should **be as simple as possible, but not simpler.**” – Einstein
- Occam (of Razor fame – **parsimony, economy, succinctness** in logic/problem-solving)
 - “Entities should not be multiplied more than necessary”
 - “Of two competing theories or explanations, all other things being equal, **the simpler one is to be preferred.**”
- Mikhail Kalashnikov (of AK-47 fame)
 - “All that is complex is not useful. **All that is useful is simple.**”
- “**Perfect is the enemy of good**”
 - https://en.wikipedia.org/wiki/Perfect_is_the_enemy_of_good

Course Recap & Game Oscars

2019-11-25

CIOS: The Course Instructor Opinion Survey

- Please do CIOS: <http://gatech.smartevals.com>
 - Disclaimers: <https://www.academiceffectiveness.gatech.edu/resources/cios/>
 - **Please complete.** I take them seriously and use them to improve my methods
 - Should only take 10 to 15 minutes, tops.
- **Surveys are anonymous**, and instructors do not see survey results until 5 days after grades are due. Also, please address comments directly to your instructors. Comments for your regular instructors are shared only with those instructors (not with school chairs or other administrators, as they see the numerical results only), while **comments for your TAs are shared with both the TA and their supervising instructor.**

| Eval | Course Prefix | Course Number | Sec | Type | Name | Begin | End | Not Resp. | Resp. | Tot. |
|-------------------------|---------------|---------------|-----|------|---------|-------|-------|-----------|-------|------|
| Preview | CS | 4731 | A | A | Game AI | 11-25 | 12-15 | 88 | 0 | 88 |
| Preview | CS | 7632 | A | A | Game AI | 11-25 | 12-15 | 53 | 0 | 53 |

Announcements

- HW 8 due December 2, 23:55
- FINAL EXAM:
 - Friday, December 6, here. 2:40 PM - 5:30 PM
 - Similar in nature to midterm.
 - Closed book
 - Can bring 2 pages, 8.5"x11", both sides
 - 15 questions
 - **1 EC worth 2xCIOS response rate**
 - Not cumulative. Included:
 - PCG, Flow, Player models, Search-based optimization (GAs, etc), Q-Learning, Grammars, MCTS, N-grams & CBR

Learning and action prediction

1. N-grams: Increasing the window size helps initially, but hurts later. Why?
2. What is a hierarchical N-gram and what does it do?
3. What are the 4 processes, each beginning with an "R", commonly used to describe the CBR methodology?
4. The _____ metric is used to find the problem/solution pair in the casebase most related to the new problem, by comparing the relatedness of the features of the new problem to the features of known problems in the casebase.
5. What are some advantages of CBR? Disadvantages?
6. A foundational assumption in CBR is that "Similar problems have _____".

~9minutes in – <https://www.youtube.com/watch?v=Etj5ykJugwU>

Game Tree Search

1. What is a zero-sum game?
2. How does this relate to minimax?
3. What is the mini and the max in minimax, as related to search?
4. What is the role of an evaluation function in minimax?
5. What are challenges with using minimax for 3+ players?
6. Can minimax handle chance elements? If not, how do we fix?
7. What is the depth of MCTS tree search?
8. Four main steps of MCTS?
9. What's the role of upper confidence bounds (UCB) in MCT?
10. MCTS converges to ____ which converges to __ in 2p zero-sum games?

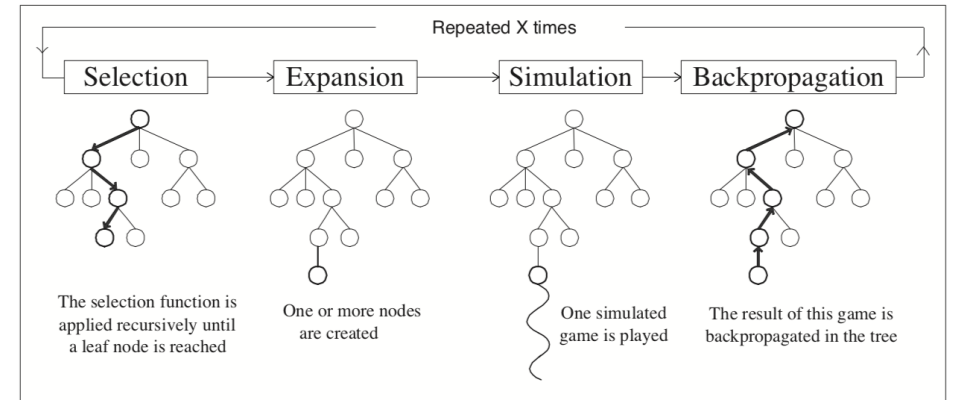


Fig. 1. Outline of a Monte-Carlo Tree Search.

CBR: Takeaway

1. Sometimes natural (e.g., law, diagnosis)

2. Cases simplify knowledge acquisition

- Easier to obtain than rules
- Captures/shares people's experiences

3. Good for some types of tasks

- When perfect models are not available
 - Faulty equipment diagnosis
 - Online sales
 - Legal reasoning
 - Games

4. Commercial applications

- Help-desk systems (e.g., Inference corp.: +700 clients)

5. Similar problems have similar solutions.

- Retrieve, Reuse, Revise, Retain

Decision Learning in M&F

- See Millington & Funge
 - 7.4 through 7.8
- Naive Bayes classification (7.5)
 - Try first, simple to implement
 - Good baseline
- Decision tree learning (7.6)
 - Output is interpretable
- Reinforcement learning (7.7)
 - “hot topic in game AI”
 - “a good starting point is the Q-learning algorithm. Q-learning is **simple to implement**, has been widely tested on non-game applications, and can be **tuned without a deep understanding of its theoretical properties**” (p631)
- Neural Networks (7.8)
 - “**Very little neural network theory is applicable to games, however**” (p646)

What did AI provide?

- Spy Party
 - background **NPCs to mimic**
- The Restaurant Game
 - act out role **w/open-ended interactions**
- Prom Week
 - rules for **social interaction mechanics**
- Petalz
 - produce new items to trade / show off
- Black & White
 - guide pet learning / raising
- Creatures
 - guide pet learning / society

What AI was used?

- Spy Party – scripting
- Restaurant Game – planning + CBR
- Prom Week – rule-based systems
- Petalz – neural nets
- Black & White – decision trees + RL
- Creatures – neural nets

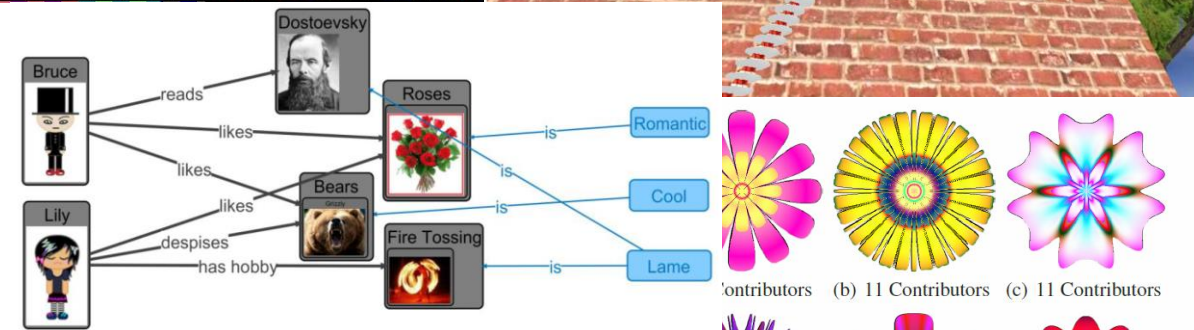


Figure 2 A small example cultural knowledge base for Bruce and Lily.

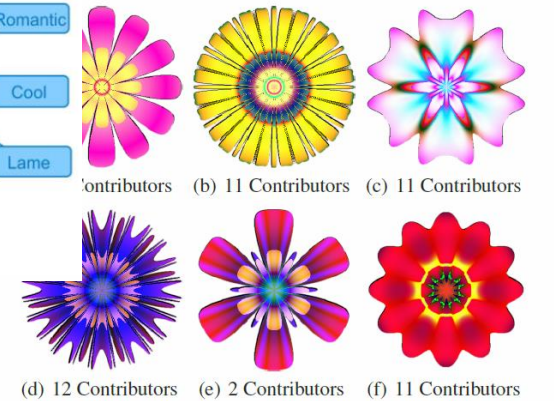


Figure 5: Evolved Flower Examples. The CPPN-based fitness allows the fitness of a population of



Where to find out more...

- Attend hack-a-thons
- Get involved in Interactive Computing experiments
- Read AIGPW, Game AI Pro (Rabin)
- AIGameDev.com, Gamasutra.com, gameai.com, aiwisdom.com, gamedevelopment.tutsplus.com
- See what has been written about your favorite games
- Attend GDC – Game Developers Conference, <http://www.gdconf.com>
 - Your favorite game AI conference is expanding to become the largest conference worldwide about Artificial Intelligence applications in interactive media, training & simulations, and digital entertainment: Meet the new nucl.ai conference
 - <http://nucl.ai/> , <http://gameaiconf.com/?nosplash>
- Play with Unity (free), Unreal Engine 4 (free), Source (free)

Game AI Oscars: ~10 years of GAI

Disclaimer: I did not write the text or generate the images on many of these “Oscar” slides. This is a compilation of material from AiGameDev.com that is actually called “Games of the Year”, and the Game Developers Choice awards

The BLUF

- Tried and true is still tried and true. FSMs, Behavior Trees, etc
- Hot topics and recent wins:
 - Reinforcement Learning, neural networks and deep learning
 - MCTS
 - Automated Planning for long-living NPCs, smarter reactions
 - PCG (!)
 - Mimicry (for 'shadow ai') & companion AI
 - Drama management
 - Crowds, open worlds

Game AI Oscars 2018-9

- RL methods have achieved significant successes:
 - Atari, Mario, Quake III Arena CTF, Dota 2, Chess, Shogi, Go
- DeepMind
 - AlphaStar achieves grandmaster in StarCraft II (and 10-1 against pros)
 - AlphaZero beats Stockfish after training for 4 hours
 - AlphaZero beats elmo in Shogi after training for two hours
 - AlphaZero beats AlphaGo Zero after 34 hours of self-learning
- OpenAI Five
 - Defeats team of professional Dota 2 players and 99.4% of online players
- 2019. “Rough year for professional gamers. Great year for AI research.”
 - OpenAI’s Dota 2 and DeepMind’s AlphaStar have outright or almost beat the best gamers with limited handicaps.
 - Not algorithmic breakthroughs. Scaling DRL
 - See below link for discussion on Inverse Reinforcement Learning

Mark Riedl, an associate professor at Georgia Tech, found Thursday's news exciting but not jaw-dropping. "We were pretty much to a point where it was just a matter of time," he says. **"In a way, beating humans at games has gotten boring."** (2019-01-25)

All the same, AlphaStar illustrates a limitation of today's highly specialized machine learning systems, says Julian Togelius, a professor at NYU and author of a recent book on games and AI. Unlike its human opponent, DeepMind's new champion **can't play at full strength on different game maps, or as different alien races in the game, without extensive further training. Nor can it play chess, checkers, or earlier releases of StarCraft.**

<https://www.wired.com/story/deepmind-beats-pros-starcraft-another-triumph-bots/>

Game AI Oscars 2017

- May of 2017, AlphaGo "Master"
 - took on Ke Jie, the world's highest ranked Go player. Over three games the machine **comprehensively dominated the world champion**
- October: AlphaGo Zero, learning entirely from self-play
- December: [AlphaZero](#)
 - **“master a variety of games in just hours.** After merely eight hours of self training the system could not only beat prior versions of AlphaGo Zero, but it also could become a chess grandmaster and a shogi champion.”

<https://www.wired.com/2017/05/want-glimpse-power-ai-play-games/>

<https://newatlas.com/ai-2017-beating-humans-games/52741/>

- January 2017: CMUs Libratus AI system
 - after nearly a month of full-time gameplay Libratus was up by US\$1.7 million, with every one of the four professionals having lost thousands of fictional dollars
 - December 2016: [U Alberta's DeepStack](#) “first computer program to beat professional players in heads-up no-limit Texas hold'em poker.”
- August 2017: Elon Musk's OpenAI team trains DOTA2 bot for 2 weeks
 - subsequently beat several of the world's top players, first ever to do so in competitive eSports



Follow

OpenAI first ever to defeat world's best players in competitive eSports. Vastly more complex than traditional board games like chess & Go.

5:15 PM - 11 Aug 2017

10,914 Retweets 36,825 Likes



But is it fun?

- Danish grandmaster [Peter Heine Nielsen](#) likened AlphaZero's play to that of a **superior alien species**
- Norwegian grandmaster [Jon Ludvig Hammer](#) characterized AlphaZero's play as "**insane attacking chess**" with profound positional understanding
- DeepMind's [Demis Hassabis](#), a chess player himself, called AlphaZero's play style "alien", "like chess from another dimension"
- Google acquires deep learning startup called Maluuba, incorporates into DeepMind group
 - Hybrid Reward Architecture (HRA) method applied to Ms Pac-Man: achieves a top score of 999,990 (higher than any human or AI)

Game Developers Choice Awards

- Best technology, 2017: Horizon Zero Dawn
 - Same studio as Killzone 3 (**HTNs**)
- Audience award: Nier Automata
- Innovation: Gorogoa
 - Puzzle, art, mobile experience
- Best technology, 2016: Uncharted 4, A Thief's End
 - Improved enemies: able to **react to the player's actions** more responsively, coordinate **tactics**, and **cooperate** with each other
 - Improved **companion AI**
- Audience award: Battlefield 1
 - EA has started training AI agents in Battlefield 1
 - **imitation learning and reinforcement learning**
- Innovation: No Man's Sky
 - PCG for stars, plants, flor, fauna...

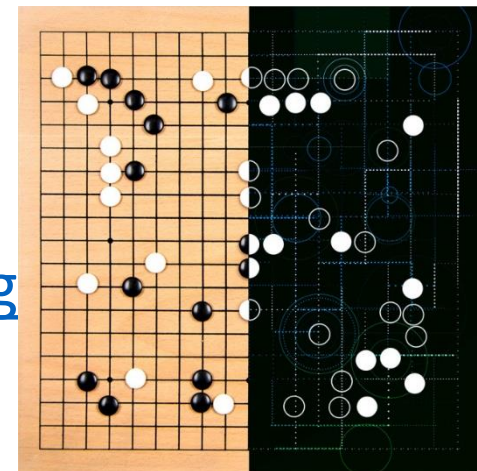
<https://www.theverge.com/2018/3/22/17150918/ea-dice-seed-battlefield-1-ai-shooter>

<http://thegameawards.com/2016/nominees/>

https://en.wikipedia.org/wiki/Game_Developers_Choice_Awards

Game AI Oscars 2015

- October 2015, Google's DeepMind AlphaGo beats Fan Hui 5-0
 - Fan Hui is a three-time European Go champion
 - First program to beat professional human Go player without handicaps on a full-size 19x19 board
 - Distributed version: 1202 CPUs and 176 GPUs
 - <http://www.nature.com/nature/journal/v529/n7587/full/nature16961.html>
- March 2016 beats Lee Sedol, 4-1
 - Lee Sedol one of the best players at Go; 2nd highest number of Go international championship victories in the world
- **Deep neural networks and Monte Carlo Tree Search**
 - Multiple training phases, both supervised and self-play
- <http://www.milesbrundage.com/blog-posts/alphago-and-ai-prog>





- can learn to successfully play 49 classic Atari games by itself, with minimal input
- *Breakout* strategy (engineering a tunnel so the ball hits the top of the screen) after being left to play the Atari game overnight. "It's now better at playing the game than any human. It has perfectly modelled this complex stream," Hassabis said at the time.
- <https://www.cs.toronto.edu/~vmnih/docs/dqn.pdf>
- <http://www.wired.co.uk/article/google-deepmind-atari>
- <http://press.nature.com/wp-content/uploads/files/2015/02/nature14236.pdf>

Categories Are

- 6 categories, each with Editors' and Community Pick
 - Best AI in a AAA Game
 - Best Non-Player Characters
 - Best AI in an Independent Game
 - Design Innovation in Game AI
 - AI in a Supporting Role
 - Technical Innovation in Game AI



2015 Winners

<http://aigamedev.com/insider/newsletter/alphago-award-results-and-nucl.ai-early-birds/>

- **Best AI in a AAA Game**

- Community Vote: Metal Gear Solid V
 - Enemies **adapt to your tactics**
- Editor's Pick: Tom Clancy's Rainbow Six Siege

- **Best Non-Player Characters**

- Community Vote: The Witcher III: Wild Hunt
- Editor's Pick: Rise of the Tomb Raider

- **Best AI in an Independent Game**

- Community Vote: Prison Architect
- Editor's Pick: Invisible, Inc.

- **Design Innovation in Game AI**

- Community Vote: Prison Architect
- Editor's Pick: Galak-Z: The Dimensional

- **AI Technology in a Supporting Role**

- Community Vote: Enemy Behavior in Just Cause 3
- Editor's Pick: Bots and Monster AI in Evolve

- **Technical Innovation in Game AI**

- Community Vote: Spawn Trees in The Witcher III
- Editor's Pick: **Case-based Reasoning, Killer Instinct**

<http://www.forbes.com/sites/erikkain/2015/09/03/12-incredible-things-about-metal-gear-solid-v-the-phantom-pain/#6591530f553f>

Game AI Oscars 2014

- <http://aigamedev.com/open/editorial/2014-awards/>
- “You can assume we either already know or have personally met the individuals behind all nominated games, and/or that their studio is a member of the site. If that's not the case, we're working on it!”
- “In 2014, we've seen many innovations in game design (for example different ways of framing battles) and AI patterns in simulations (like **AI directors and open-world systems**), as well as improvements for next-generation consoles (such as **large crowds of pedestrians or large numbers of active enemies**), **prolonged interaction** between AI and player (e.g. **persistent enemies**), and **of course procedural generated worlds.**”



Best AI in AAA Game

- Nominations

- The Sims 4
- Planetary Annihilation
- Alien: Isolation
- Middle-Earth: Shadow of Mordor
- Far Cry 4

- Honorable Mentions

- Dragon Age: Inquisition
- Assassin's Creed: Unity
- Titanfall
- Sunset Overdrive

- Community Pick:

- Middle-Earth: Shadow of Mordor

- Editors Pick:

- Planetary Annihilation



Best AI in AAA Game (CV): Middle-Earth: Shadow of Mordor

“SOM was also nominated for a variety of other awards here, ranging from game/AI design (thanks to its nemesis system) to AI technology (because of its use of **planners**) — innovating on many fronts.”

*“I think, or at least hope, that Shadow of Mordor will go down as one of the most important games of recent years for starting the trend of **giving non-story NPCs individual personalities, memories of past encounters and in many cases, a survival instinct!** All things lacking in most combat games where NPCs are nothing more than short-lived target dummies.”*

— [Richard Matthias](#)

Also nabbed Design Innovation in GAI (CV)

“The **systemic gameplay should also be noted** — when missions are failed or abandoned, **open-world gameplay continues in that state** and you can wander into random Uruk captains at any time, which **gives pre-designed missions a more organic feeling.**”

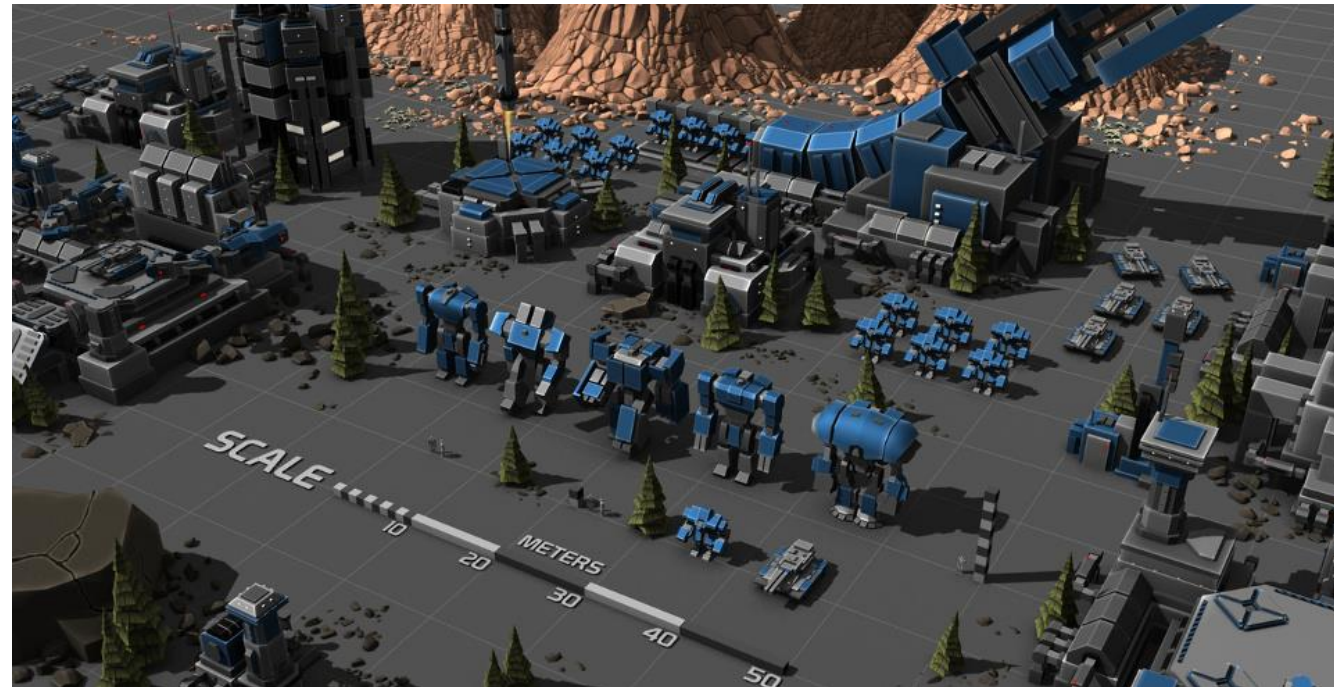
— Richard Matthias

“...its real power probably came from **proper balancing** and, what is I guess most important here, **informing player about what happened** in the Ork society, **and WHY**. Often really sophisticated systems fail to provide fun not because they're inherently broken, but because they're not **properly communicated to the player.**”

— Maciej Kurowski

Best AI In AAA Game (Editors): Planetary Annihilation

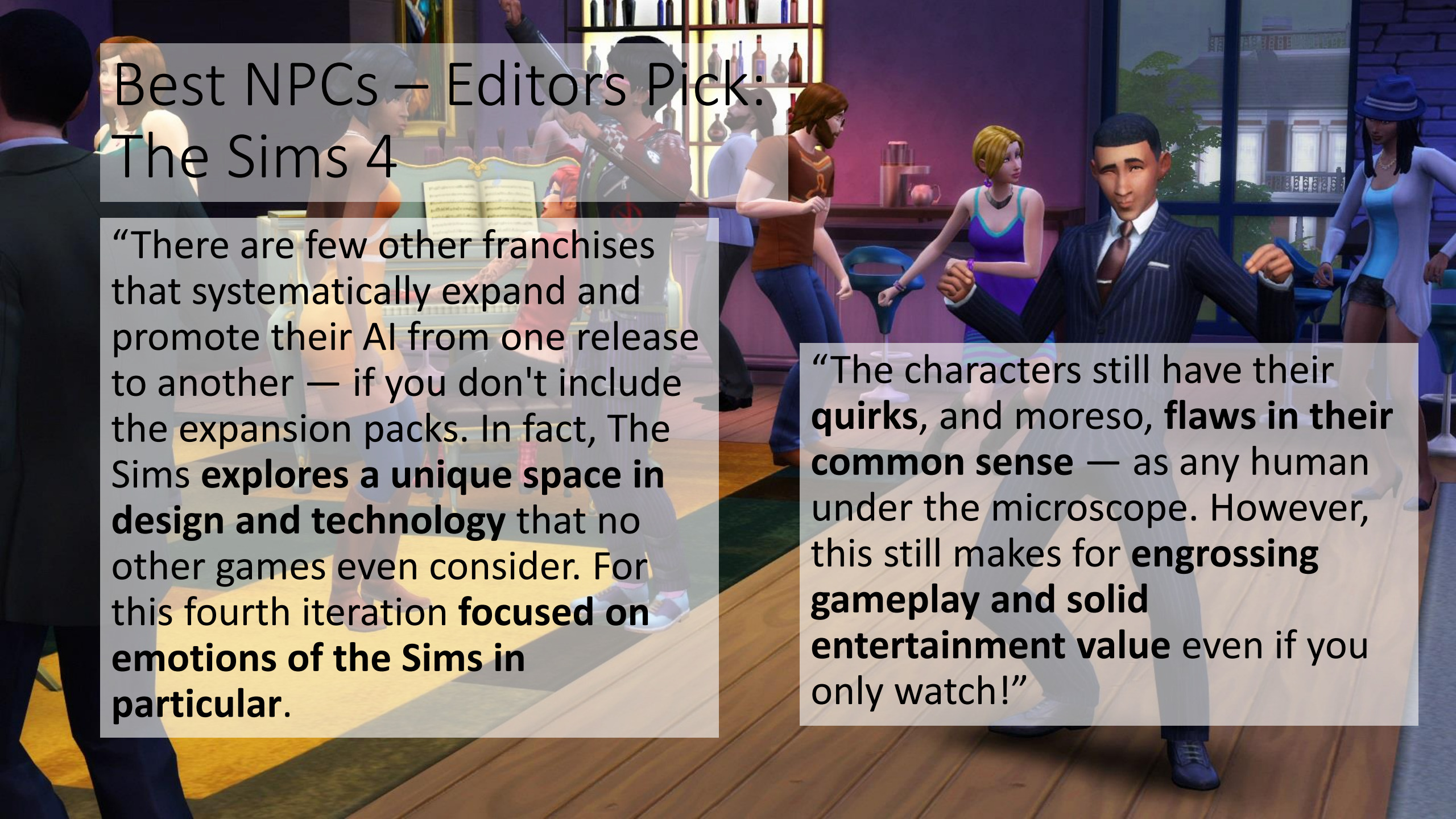
“From the AI perspective, many new challenges had to be solved by the team, in particular **inter-planetary resource allocation**, an AI that can **reason strategically** on a sphere, and **scaling up to huge number of units**. On top of this, the implementation focuses on **building a skilled AI using a neural network and a form of reinforcement learning**. This makes it interesting to play against for learning purposes and challenging while levelling up!”



Best NPCs – Community Vote: Alien: Isolation

“Alien: Isolation that won the award over Middle-Earth: Shadow of Mordor with a statistically insignificant margin”

What makes Alien: Isolation particularly interesting from an AI perspective is the Xenomorph — which **interacts with the player over the course of the entire experience**. Sustaining such a **prolonged interaction** is rare for modern games, and the **entire experience relied on its artificial intelligence**. Thankfully, it not only lived up to expectations but has often amazed the critics and players alike.



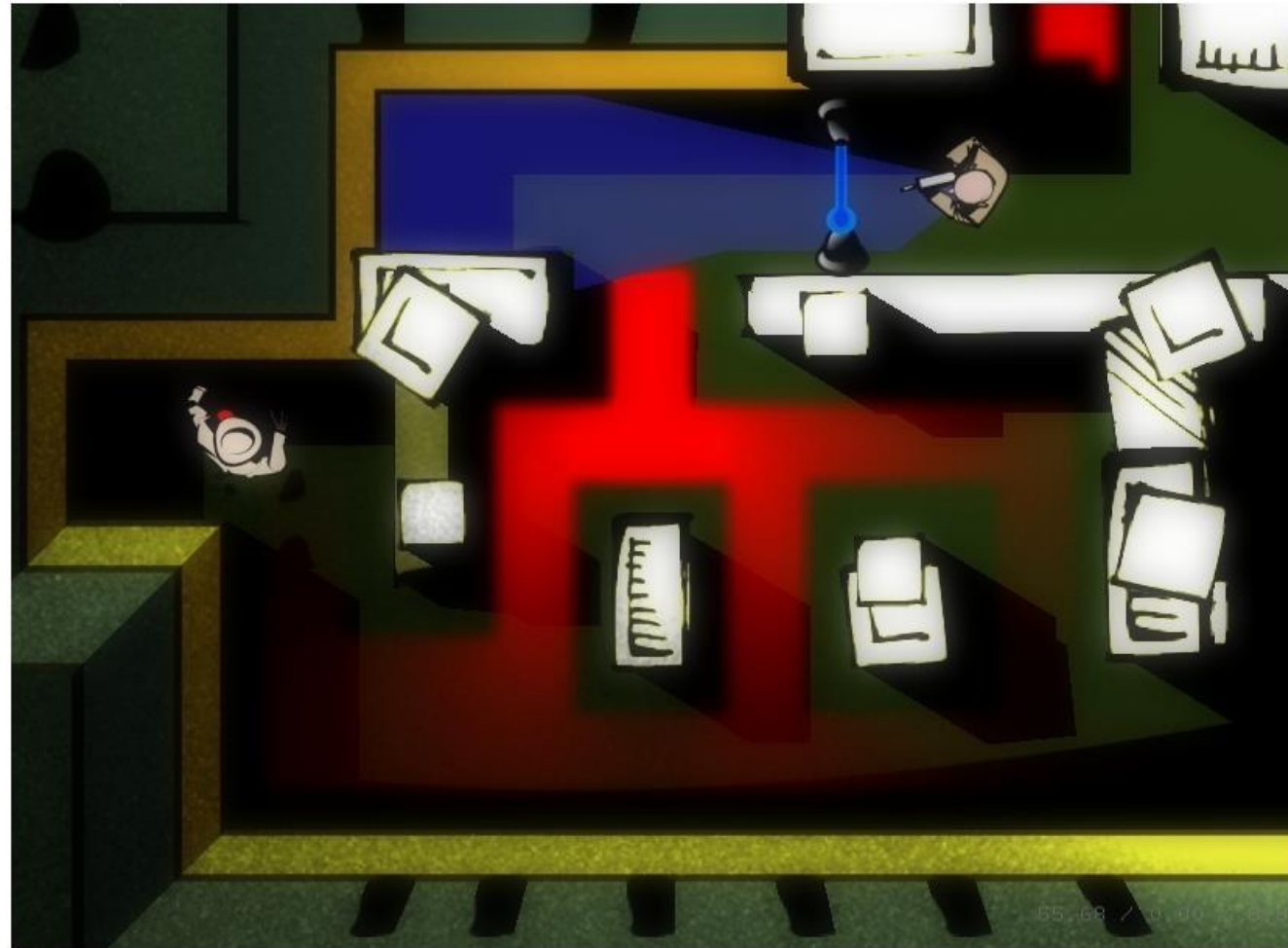
Best NPCs – Editors Pick: The Sims 4

“There are few other franchises that systematically expand and promote their AI from one release to another — if you don't include the expansion packs. In fact, The Sims **explores a unique space in design and technology** that no other games even consider. For this fourth iteration **focused on emotions of the Sims in particular.**

“The characters still have their **quirks**, and moreso, **flaws in their common sense** — as any human under the microscope. However, this still makes for **engrossing gameplay and solid entertainment value** even if you only watch!”

Best AI in an Independent Game (CV): Third Eye Crime

“It's Moonshot's long-awaited Third Eye Crime that won year's community vote for Best AI in an Independent Game. It's a stealth game where the **enemy's model of the player position is a probability distribution over the level, also known as an occupancy grid**. The game shines particularly for its clever exploration of these core mechanics via a series of puzzles over three Noir-style episodes”



PC version in particular was penned as "love letter" to the Game AI community thanks to its full Lua source release and additional debug visualizations

Best AI in an Indie (E): Banished

“Banished is a medieval city simulator developed entirely by Luke Hodorowicz. It's impressive enough for a **single developer** to have built a game of this quality, but it was also among the team's most played games of the year — filling the niche that the previous year's Sim City left open.”


“From an AI perspective, Banished solves a variety of very challenging technical problems including **efficient pathfinding** at city scale, **worker assignment in dynamic conditions**, and **scaling up to large cities**. But most importantly, its the detailed simulation of each villager that makes this a gritty "**rogue-like**" **city builder** where you feel a strong connection to your inhabitants — especially when things result in horrible and miserable endings!”

Debug

Game Disaster Statistics Environment



- Disable effects of hunger.
- Enable zero build cost.
- Disable effects of health.
- Disable effects of cold.
- Set all educated.
- PathIslands



MEMORY 37.8% OBJECTS 19.94% PERFORMANCE

Design Innovation in GAI (Editors Pick): Open World Systems in Far Cry 4

ASIAN ELEPHANT

- L ROTATE
- OBJECT OPTIONS
- DELETE SELECTION
- RESTORE ORIENTATION
- DUPLICATE
- DROP TO GROUND
- DESELECT ALL
- L1 TOOLBOX
- R1 CAMERA HEIGHT

“Each of the objects in Far Cry 4 — and the level editor — are **annotated with specific rules and behaviors**, ready for combining with other items in the map. This is similar to The Sims' **smart object** concept, but in this case the **items include their own behavior trees** which can interact with each other (e.g. animals). **Level designers** can easily build **emergent ecosystems** by combining objects together, but only the **AI team gets control of the underlying parameters and behaviors.**”



AI Technology in a Supporting Role (CV): Crowds in Assassin's Creed: Unity

“The transition to next-generation consoles brought with it increased expectations, and the latest Assassin's Creed is the first notable game to make the most of it in its depiction of revolution-torn Paris. It won this year's community vote for AI Technology in a Supporting Role thanks to its **huge crowds.**”

AI Technology in a Supporting Role (Editors): Defense of the Ancients 2 (DOTA2)

“The most notable implementation in this area is currently DOTA 2's; experienced players often praise **the bots as a great tool and recommend it to beginners.**”

“we've also seen increasing focus of bots in two places:

- Using **bots as part of the multiplayer AI**, for example as the auto-pilot AI for Titanfall.
- **Bots as beginner training tools**, for instance in Hearthstone's **practice mode.**”

[ALLIES] Hank Bot: Defending mid

```
(biped_base | fallen_base | fallen_base with fingers | auto base skeleton)
```

```
Layer: 1.00 base
```

```
Weight: 0.60 Frame: 46.78
```

```
Weight: 0.40 Frame: 15.00
```

```
Layer: 0.01 move_dip
```

```
Weight: 0.01 Frame: 4.82
```

```
Layer: 1.00 character_layer
```

```
Weight: 1.00 Frame: 1.00
```

```
Layer: 0.40 twitch_layer
```

```
Weight: 0.40 Frame: 17.00
```

```
Layer: 1.00 aim
```

```
Weight: 0.01 Frame: 1.00
```

```
Weight: 0.02 Frame: 1.00
```

```
Weight: 0.74 Frame: 1.00
```

```
Weight: 0.13 Frame: 1.00
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```
Weight: 0.09 Frame: 15.00
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```
Weight: 0.02 Frame: 1.00
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```
Layer: 1.00 look
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Weight: 0.01 Frame: 39.00
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Weight: 0.07 Frame: 1.00
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```
Weight: 0.68 Frame: 1.00
```

```
Weight: 0.06 Frame: 17.00
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```
Weight: 0.05 Frame: 1.00
```

```
Weight: 0.13 Frame: 17.00
```

```
Layer: 0.67 grip
```

```
Weight: 0.07 Frame: 1.00
```

```
Weight: 0.60 Frame: 18.00
```

Technical Innovation in Game AI (CV): Animation Rig in Destiny

“The biggest challenge in the ‘realization’ of character behaviors is by far the **animation**. You can't portray any kind of movement, gesture or emotion without a suitably animated skeleton. Bungie took the problem head on with its new cross-platform engine powering Destiny, and developed a very powerful system capable of **retargeting animations to any skeleton at runtime** — among many other things”

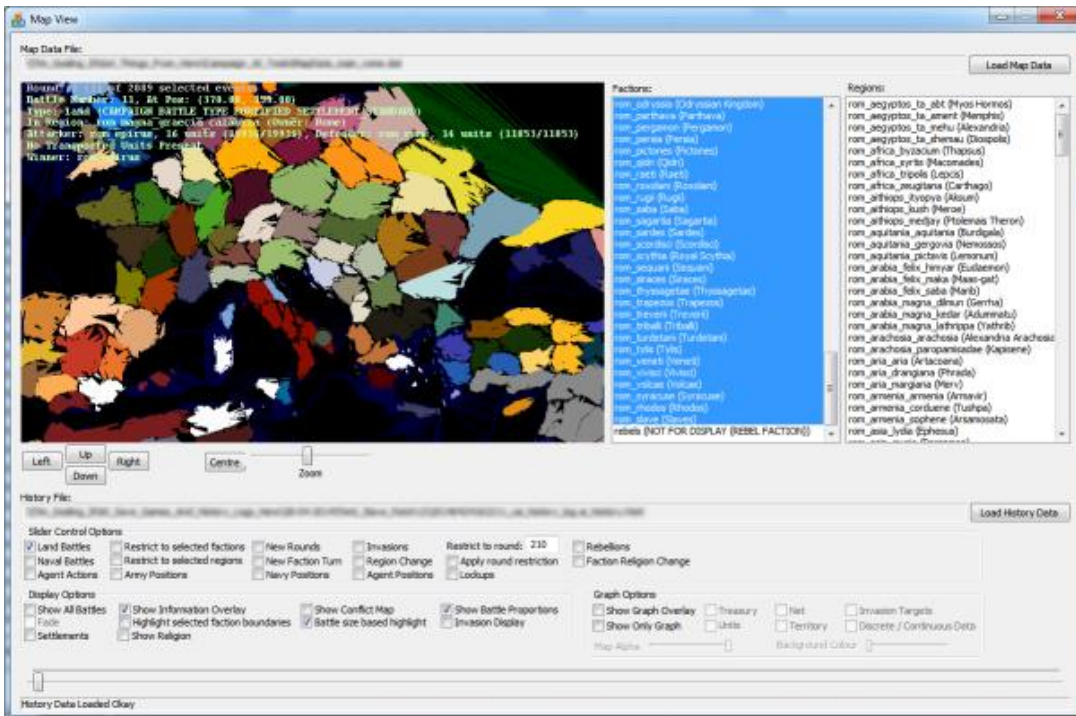
“This offers many benefits such as **runtime control (e.g. by AI)** as well as animation compression and **correctness of the results in dynamic environments.**”



Technical Innovation in GAI (Editors): Monte-Carlo Tree Search in Total War: Rome II

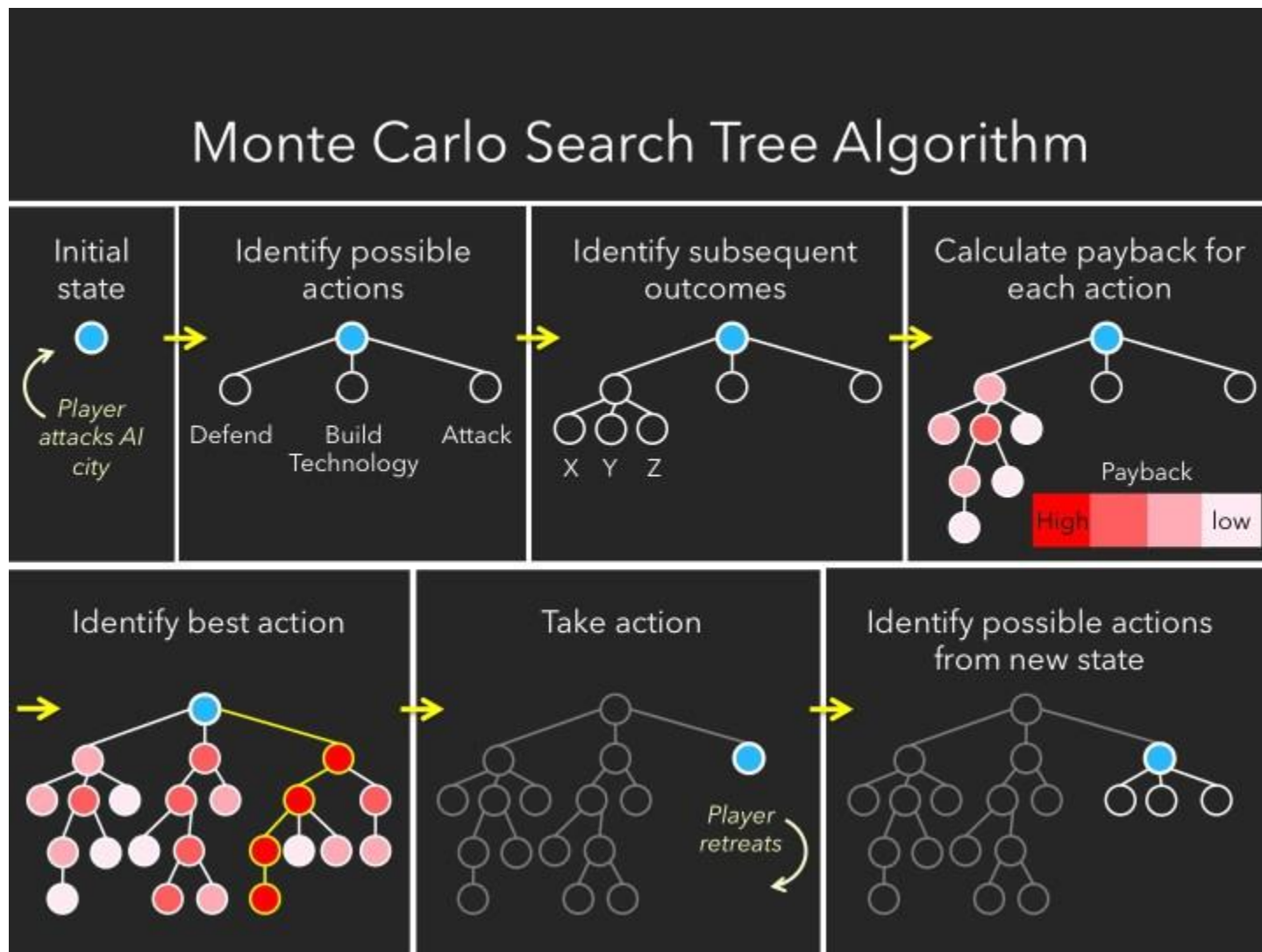
“The application of MCTS isn't necessarily noticeable by players but **it has many advantages from the development perspective.**”

“Benefits of Monte-Carlo Tree Search include the ability to **make design and balancing changes to the game itself, then letting AI adapt accordingly**, and more — as we previously covered. Compared to more traditionally scripted systems or rule-based approaches, this helps **bring us closer to the goal of having reusable AI algorithms that do all the hard work for us!**”



MCTS

A more advanced method used to enhance the personalized gaming experience is the [Monte Carlo Search Tree](#) (MCST) algorithm. MCST embodies the strategy of using random trials to solve a problem. This is the AI strategy used in Deep Blue, the first computer program to defeat a human chess champion in 1997.



Innovation Tip of the Hats, 2014

- **Multiplayer AI Enemies and Auto-Pilot AI** in Titanfall
- **Emotions** in The Sims 4
- **Goal-Oriented Action Planning** in Shadow Of Mordor
- **Practice Mode** in Hearthstone
- **Drivatar** in Forza Horizon 2
 - Shadow AI
- **Offline Mission Planning** in Planned Assault
- **Biomechanical Animation** in I Am Dolphin

Game AI Oscars 2013

- <http://aigamedev.com/open/editorial/2013-awards/>
- “Like previous years, the games this year have raised the bar in many places for artificial intelligence, **including autonomous buddy behavior, search-based techniques to find optimal moves, and non-character AI** such as music generation and learning to race cars based on human data”

Best AI in a AAA Game

Community vote:
The Last of us

- Single player action-adventure survival horror game (made Uncharted)
- features **one prominent AI character** "buddy" called Ellie, whom the player (Joel) is required to accompany through the story
- **storytelling, design, voice acting, animation and technology**, the game manages not only to avoid the usual pitfalls of escort missions, but manages to portray **incredibly rich characters with a touching and memorable relationship**

Editors Pick:
Grand Theft Auto V

- epic multi-studio achievement of the largest proportions
- city of Los Santos and its surroundings is brought to life in a way that's yet to be matched
- game breaks or the characters don't "work" as they should
- ?ambient life as capable technically as (Rockstar's) Red Dead Redemption?
- the **magnitude** of Rockstar's vision for the world only helps emphasize the importance of AI for this (and upcoming) games



Best NPCs

Community Vote:
The Last of Us

- 2011, Id Software's RAGE managed to impress AI geeks and compel players with its enemy AI that displayed great **survival behaviors**
- enemies **display a sense of self-preservation** that makes them feel more **believable** than the average NPC in-game. This includes animations to **portray fear** as well as the **cover-taking decisions**

Editors Pick:
Bioshock Infinite

- took a strong team of AI designers and programmers many hard years to pull this off
- <https://www.youtube.com/watch?v=2viudg2jsE8> (see 3:55)
- For combat, the game also uses high-level AI similar to Halo 3's objectives system to coordinate enemies

Sidebar: Halo 3 AI Objectives

“The HALO 3 AI Objectives System turns the techniques used in previous HALO games on their head: rather than a designer ordering groups of NPCs to certain physical areas and then transitioning them to other areas as the battle progresses, H3O allows the designer to specify a set of tasks in the environment and then comes up with an optimal distribution of squads across those tasks.”



<http://halo.bungie.net/inside/publications.aspx>



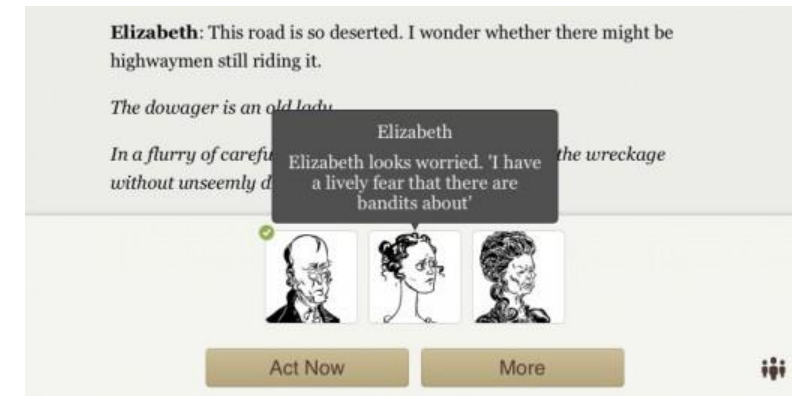
Best AI in an Independent Game

Community Vote: Versu

- best described as **part game / part story**, as a digital interactive version of the **Choose Your Own Adventure** books powered by one of the industry's most sophisticated **social models**
- interact with it via a set of actions that you can perform at any time as the simulation continues, or sometimes when prompted. It's a style of experience quite unlike any other out there

Editors Pick: Prison Architect

- attention to details that earns Prison Architect its award.
- From the **different needs and drives of each prisoner**, to way they dig tunnels to **escape**, or their **behavior** in kitchens / canteens / laundries.
- Introversion's approach of providing early access and iterating over the behaviors/AI based on feedback



Design Innovation in Game AI

Community Vote:
Clumsy Ninja

- Perceptual Control Theory
- game features an interactive and active "ragdoll" that responds to your various actions; you can hit, pull, drag, throw your little Ninja
- **respond physically but also behave accordingly**
- added these Ninja behaviors to increase **engagement and interaction**

Editors Pick:
Warframe

- **procedural generation** of entire spaceships based on individual building blocks, an **AI director** that controls the action by **spawning enemies** as appropriate, a **variety of enemy behaviors** from melee to ranged attacks, and of course **match-making algorithms**



AI Technology in a Supporting Role



Community Vote:
Drivatar in Forza Motorsport 5

- feature in previous Forzas, but Microsoft's **cloud computing brought more attention**
- all computer-controlled opponents are **modelled on other human beings** and inserted into the game with their **personas/personalities clearly on display**
- clever way to enable **non-realtime multiplayer collaboration** by sharing your trained AI with friends

Editors Pick:
Jam Mode in Rocksmith

- **generative audio** in jam mode, where **simulated band members** play together — both **driving the improvisation and adapting** to the player
- may seem like a relatively **simple system under the hood**, as indeed **most AI in games is!**

Technical Innovation in Game AI

Community Vote:
MCTS in AI Factory

- broad range of **board and card games** have been downloaded over 40 million times on Android
- underlying implementation that's based on **Monte-Carlo Tree Search**; uses a combination of math and brute force to calculate good moves

Editors Pick:
Agent-based City Sim

- simulation of the **many-to-many "exchanges"** in a city cannot be reduced down to a set of single-source pathfinding calculations
- Design flaws and technical issues
- Sim City's **large scale agent-based approach** is still one of the most innovative and bold ideas to be implemented in a game



Innovation Tip of the Hats, 2013

- **World Generation** in DON'T STARVE
- **Social Behavior** in RED SHIRT
- **Plan Compilation** in KILLZONE: SHADOW FALL
- **Neural Networks** in DEMOCRACY 3
- **Agent-based Simulation** in SIM CITY
- **Fish Simulation** in CALL OF DUTY: GHOST
- **Ambient AI** in ASSASSIN'S CREED: BLACK FLAG

Game AI Oscars 2012

- <http://aigamedev.com/open/editorial/2012-awards/>
- AI-based mechanics that open up new game designs
- using optimization and evolutionary algorithms as tools,
- procedural pipelines for AAA-quality graphics



Best AI in AAA Game

Community Pick:
XCOM: Enemy Unknown

- impressed AI geeks **with tactical reasoning** that was very solid yet **could be surprised and caught off guard** by the player
- **emphasizes that great game AI and great mechanics go hand in hand**, but that best-in-class **game design is often a sufficient condition for winning** the public's opinion about the AI — almost more so than technical innovation

Editors Pick:
Far Cry 3

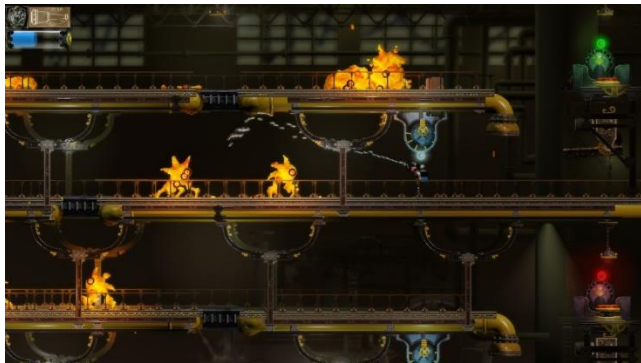
- featured **iconic and memorable characters**
- applications of AI, from the **wild-life** to the **combat manager that spawns enemies**, and of course its NPCs
- Building open-world games is a huge challenge in general ... turn the island into the main feature of the game



Best AI in an Independent Game

Community Pick:
Vessel

- Innovative use of **combinations of behavior** in gameplay puzzles, to the **underlying simulation of the characters that blend skeletons and fluid simulations**, as well as the **dynamic music and audio which adjusts to the player's progress**
- **character behavior can make interesting gameplay**



Editors Pick:
Prom Week

- Expressive Intelligence Studio at the University of Santa Cruz
- takes the idea of **story as a simulation** further by adding the concept of "**social physics**", i.e. **predictable character mechanics** that the player can interact with for gameplay purposes
- underlying system, *Comme Il Faut* is well documented via multiple publications, and emphasizes how many opportunities there are still in this area



Design Innovation in Game AI

Community Pick:

Crowds in Hitman: Absolution

- First and foremost, the underlying **crowd-simulation technology** that IO Interactive built brings scenes to life in a way previously unseen in AAA games
- crowds also add to the gameplay, **providing obstacles and concealment**, as well as **responding to gunfire in a plausible way**



Best NPCs

Community Pick:
Hitman: Absolution

- statistically insignificant margin in front of FAR CRY 3
- **reinforcement-learning for animation control, grid-based reasoning** inspired by KILLZONE's technology and a **behavior-tree implementation of classic stealth AI**



AI Technology in a Supporting Role



Community Vote: Physics-Driven Motion in Max Payne 3

- AI in animation system
- result is a **highly interactive protagonist** that you can throw down stairs while controlling his movement, and yet still **respond to collisions in a reasonable way**
- requires significant support from AI-style reasoning **to understand the immediate surroundings of falling characters**, and determine how to **respond at a high-level**, then **affecting control on the underlying simulation**

Editors Pick: Evolutionary Algs in City Conquest

- tower defense game that features **symmetrical gameplay** against opponents
- used **evolutionary algorithms** as part of the design process to help **balance and tune the various units and towers** in the game (among others)
- **Tools** seem like an ideal place for GAs and Quake 3 in particular had some of its **weapon selection parameters evolved**.

Technical Innovation in Game AI

Community Pick:
Hierarchical Planning in Transformers: Fall of Cybertron

- Features a **HTN planner**
- accurately **tracks side-effects of operators** on the world. For non-planning geeks, this is a subtle improvement, and furthermore it **can be hard to distinguish a planner from a behavior tree in practice** (especially in action games). But the result of this vote also **hints at the general appeal to the public of planning as a concept!**

Editors Pick:
Procedural Pipelines in SSX

- **PCG of mountains and tracks**
- Arguably the most important technical innovation this year, from our perspective at AiGameDev.com, is the **inclusion of procedural techniques within AAA pipelines to produce top-quality graphics**
- used the pipeline entirely to craft the tracks, and **only the final artist touch up was done manually**. The developers **hope and plan to go 100% procedural** with better education/training in the future! Expect this technology to spread around Electronic Arts and the rest of the industry incrementally as well



Innovation Tip of the Hats, 2012

- Behavioral Gameplay in VESSEL
- Enemy Steering in FIELD RUNNERS 2
- Supervised Flower Breeding in PETALZ
- Reinforcement Learning Animation in HITMAN: ABSOLUTION
- Evolutionary Algorithm as Design Tool in CITY CONQUEST
- Bots AI in DOTA 2
- Language Recognition in SCRIBBLENAUTS UNLIMITED
- Tactical Reasoning in XCOM: ENEMY UNKNOWN

Game AI Oscars 2011

- <http://aigamedev.com/open/editorial/2011-awards/>
- better integration of the AI and gameplay
- overall polish of the character behaviors
- applications of artificial intelligence to other areas of games



Best AI in a AAA Game

Community Pick:
Batman: Arkham City

- features **fluid animations** between the player and the endless hordes of brutes in the game as well as **environment interactions**
- smooth movement in combat obviously require AI for the NPCs, but increasingly animation systems are scaling-up significantly and using techniques refined by game AI developers

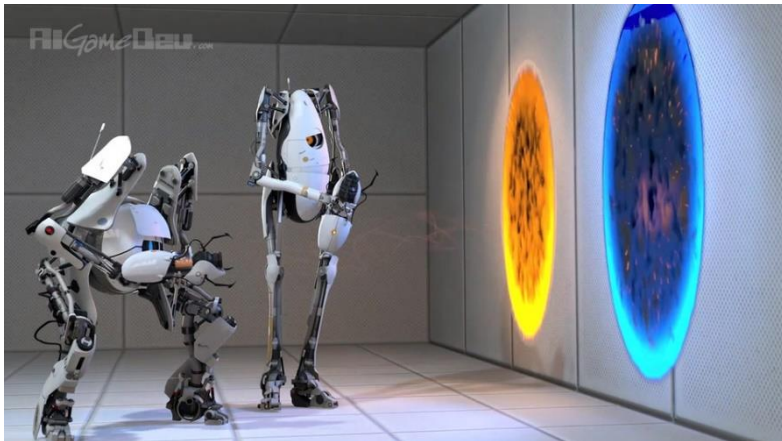
Editors Pick:
Resistance 3

- Insomniac's work is notable for iterating over the enemies in the game — and introducing new ones — that fit best with the desired gameplay
- team put **AI hand in hand with combat design**, a solid understanding of level design, and a **high-level AI reminiscent of RTS games, and AI directors** that allows the **designers to shape gameplay**
- using the open source Recast library for navigation

Best NPCs

Community Pick: Portal 2

- portrayals of GLaDOS and Wheatley in particular
- While there **isn't much AI behind the characters** in PORTAL 2 as many of them obviously rely on scripts, it's inspiring to think about how such **simple animation techniques can combine with well written dialog to portray rich characters**



Editors Pick: Uncharted 3

- expertly refined and tuned its techniques for **portraying game characters** as genuine and interesting characters
- The addition of the **close combat system** in UNCHARTED 3 also increases their levels of **believability**, not to mention the combinations of **interactive animations** and prepared cutscenes.
- UNCHARTED 3 also features one of the **richest walk cycles ever seen in a game**, in the way player avatar **interacting with its environment** and uses varied animations based on where the character is looking



Design Innovation in Game AI

Community Pick:
Dark Spore

- **AI Director; experience management and player profiling** have become increasingly important recently, as more developers try to make their gameplay a bit less chaotic and **closer to what the designer intends**
- enemies in the game are **spawned based on the player's state** — among other things. The game also uses this approach to **adjust difficulty levels** based on the player's selection

Editors Pick:
Swarm

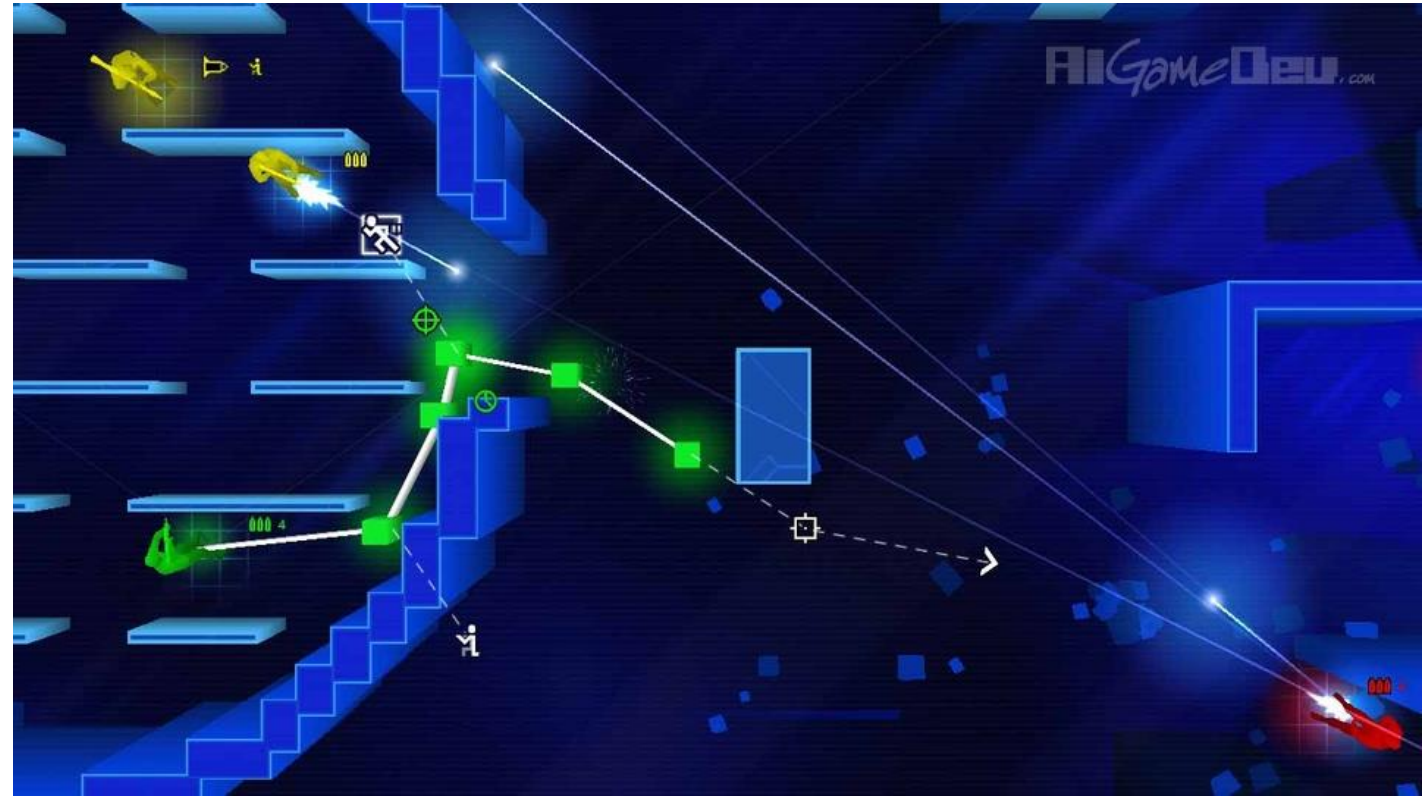
- fascinating merge of **Lemmings** and **'boids'** with **flocking behaviors**, challenging you to control a group of Swarmites through hostile terrain
- **basic combination of group behaviors** that lead to interesting, challenging and — most importantly — **fun** gameplay



Best AI in an Independent Game

Community Pick: Frozen Synapse

- One of the most acclaimed and commercially successful indie games of 2011
- turn-based top-down tactical shooter with challenging gameplay and very deep mechanics.
- features AI bots to play against, which are relatively rare in even big-budget AAA games



AI Technology in Supporting Role

Community Pick:
From Dust

- **cellular automata** in Ubisoft and Eric Chahi's god game for ps3
- Ever changing world subject to the forces of nature: rock, sand, soil, water, lava and plants



Technical Innovation in Game AI



Community Pick: Killzone 3

- integrated the open-source project Recast into its tools and export pipeline to provide better analysis of the terrain
- This helped level designers **place cover locations** for the player in a much more consistent fashion
- can also be used **to find jump links** and potentially any interesting **action that can be performed at the border of a navigation mesh**

Editors Pick: Bulletstorm

- **Locomotion planning and execution** is achieved in an animation-driven approach that's targeted to **fit on a path**
- **Compared to the traditional steering behaviors with reactive animation**, this is not only much **easier** to put into place for AI characters but results in **higher quality movement**

Innovation Tip of the Hats, 2011

- Procedural Worlds in MINECRAFT
- Level Scripting with BTs in LEAGUE OF LEGENDS
- Squad AI in SPACE MARINE
- The Narrator in BASTION
- Enemy Spawns in RIFT
- The Bots in SECTION 8: PREJUDICE

Previous Years

- <http://aigamedev.com/open/editorial/2010-awards-results/>
- <http://aigamedev.com/open/editorial/2009-awards-results/>
- <http://aigamedev.com/open/awards/2008-results/>
- <http://aigamedev.com/open/awards/2007-results/>

Game AI: Recap

2019-11-25

Game AI: The set of algorithms, representations, tools, and tricks that support the creation and management of real-time digital experiences

Motivations

- gain a breadth of understanding of the toolbox of AI approaches employed in digital games
- focus on applied knowledge within the context of digital games
- understand how a game design can be brought into existence through the application of algorithms that are often thought of as intelligent

Learning Objectives

Students in this course will:

1. ... gain a breadth of understanding of current issues and techniques in academic and industry game AI.
2. ... have hands-on experience in working with different game technologies and incorporating AI programming techniques within those technologies.
3. ... be capable of implementing some of the most common Game AI techniques used in industry today
4. ... better understand the relationship between game AI and aesthetics, narrative, and player experience
5. ... have an understanding of and appreciate the distinctions between artificial intelligence techniques adopted by the computer game industry and those being pursued in research labs and non-games related industries

What is...

- GAI?
 - Set of tricks and techniques to bring about a particular game design.
 - Goals include:
 - **enhancing the player's engagement, enjoyment, and experience**
 - End behavior is the target
 - Do better than random
 - **doing things the player or designer cannot do or don't want to do**
 - replace real people when they are unwilling or unavailable to play
 - aid for designers and developers
 - making the entities, opponents, agents, companions, etc. in games **appear** intelligent
 - **believable** characters / **looking convincing**
- A Game?
 - A system of rules and a goal and agency.

How/Why distinct from “academic AI”

- Good game AI == **matching right behaviors to right algorithms**
- **Product is the target**, not clever coding – ends justify means. FUN
- **Illusion** of intelligence
- “Magic Circle” (Rules of play: game design fundamentals)
- **Elegance in simplicity & the complexity fallacy**
- **Quality control** & resource limits
- **Fun vs smart**: goal is not always to beat the player
- Optimal/rational is rarely the right thing to do

Common “GAI” Tricks

- Move before firing – no cheap shots
- Be visible
- Have horrible aim (being Rambo is fun)
- Miss the first time
- Attack “kung fu” style
- Warn the player
- Tell the player what you are doing (especially companions)
- React to own mistakes
- Pull back at the last minute
- Intentional vulnerabilities or predictable patterns

Common “GAI” Techniques

- Path planning, obstacle avoidance
 - Tile-based graph (“grid navigation”)
 - Path Networks / Points of Visibility NavGraph
 - Expanded Geometry
 - NavMesh
- Decision making
 - Finite state machines
 - Trigger systems
 - Decision & Behavior trees
 - Rule-based systems
 - Planning
 - Reactive Planning
 - Blackboards
- Command hierarchies—strategic, tactical, individual combat
- Action prediction
- Search
 - Precompute: Dijkstra & Floyd-Warshall
 - Live: A*, Hierarchical A*, RTA*, RTA* + lookahead, D* lite
 - Large: Genetic Algorithms, MCTS, Hill Climbing, minimax, alpha-beta pruning, expectiminimax
- (Kinematic & Steering) Movement
 - Emergent behavior—flocking, crowds
 - Steering, Flocking, Formations
 - Terrain analysis—finding resource, ambush points
- Smart environ’s, Scripting, Trigger systems
- Designer intent
 - Dynamic difficulty adjustment
 - Drama management
- Procedural Content Generation
- Player Models: Robin, Bartle, Yee

Learning in GAI?

- Potential to (in principle)...
 - Adapt to each player
 - Provide consistent challenge
 - Produce more believable characters
 - Reduce effort to create game-specific AI
- In practice
 - Falls short, and not for want of trying
 - Hype more attractive than reality
 - Not widely used → **Reproducibility & QA**
- Advice: **Be aware of the hype**
 - Unpredictability motivates curbing learning ability
 - Often impossible to avoid learning “wrong” thing
 - Behavior might fulfill goals but make terrible gameplay
 - Cake/Eat: ↑ learning **flexibility** == ↓ **control** gameplay
 - Overfitting vs Generalization
- Sol’n: **Constrain** learning task (e.g. cover pts)
 - Problem decomposition (again!)

Communication in Decision Making?

- Lens: Multi-agent system
 - Collection of collaborative agents
 - Communicate & cooperate
 - Retain autonomy
 - Need for negotiation / mutually acceptable agreements (cooperative problem solving)
- Reasoning decomposition: distributed expertise
 - Problems too large for single / centralized agent
 - Reactive agents rarely communicate / collaborate
 - Problem independence, partial result sharing
- Hope: Sum greater than parts

- Distributed Decision Making:
 1. Decompose the task
 2. Allocate subtasks to “experts”
 3. Await task accomplishment
 4. Synthesize & Arbitrate results

Information sharing needed for most/all!

Design-time vs Run-time PCG?

- Design time: Speed up design of static content
 - # of unique objects in the world
 - Players expect non-repetitive
 - Game dev times now 100s of man-years with huge design teams
 - Cost savings big motivation
 - RISKS: quality (designer) control, stupidity, magic circle
- Run-time: customization, dynamic adjustment (flow)
 - Players are different: Preferences for pace + playstyle
 - Moderate challenge levels (e.g. help avoid getting stuck)
 - Adjust to play style
 - Detect/avoid player exploits
 - When to use run-time PCG
 - When decisions can only be made at run-time
 - When pre-compute exceeds storage/memory limits
 - Replayability; story/quest generation; pacing;
 - Optimization problem
 - What is the set of content that delivers the optimal experience to the player given individual differences?

Game AI By Genre

- FPS
 - Movement
 - Decision making
 - Perception
 - Pathfinding
 - Tactical AI (e.g. Halo)
 - Drama management (e.g. L4D)
- Driving Game
 - Movement & Steering Behaviors
 - Pathfinding
 - Tactics
- Sports
 - Physics (projectile) prediction
 - Playbooks and Content Creation
 - Formation movement
 - Expert knowledge
- RTS
 - Pathfinding
 - Group movement
 - Tactical & Strategic AI
 - Decision making
- Turn-based
 - Similar to RTS AI
 - Timing: AI at disadvantage
 - Player assistance
 - Automation of repetitive tasks
 - Automation of decision-making

Game Oscars: What's hot in game AI

- **AI directors & Designer intent**
- Behavior Trees
- Planners (HTN and otherwise)
- MCTS
- Mimicry/shadow ai; companions
- Open-world systems
- Scale, large numbers active; crowds
- **Prolonged interaction**, Persistent enemies, NPC personalities & memories
- PCG
- AI with survival instinct
- Evolutionary algorithms
- Reinforcement learning
- Neural networks
- Interactive fiction
- Smart worlds/objects
- Believable movement
- PCG
- Player models and dynamic difficulty

2017: The year academic AI beat humans at their own game(s). 2019: academic AI beats itself

Takeaways

- **Simplicity & speed**
- Non-determinism (& random seed)
- Inform player about what is going on and why
- Hierarchies help
- Heuristics help. A lot.
- Illusion of intelligence
- **Search**
- (Graphs & other) **Models**
- “Everything should be as simple as possible, but not simpler.” – Einstein
- Occam (of Razor fame – parsimony, economy, succinctness in logic/problem-solving)
 - “Entities should not be multiplied more than necessary”
 - “Of two competing theories or explanations, all other things being equal, the simpler one is to be preferred.”
- Mikhail Kalashnikov (of AK-47 fame)
 - “All that is complex is not useful. All that is useful is simple.”
- “Perfect is the enemy of good”
 - https://en.wikipedia.org/wiki/Perfect_is_the_enemy_of_good

Thank you! Candid feedback welcome
(can do anonymously)

CIOS: The Course Instructor Opinion Survey

- Please do CIOS: <http://gatech.smartevals.com>
 - Disclaimers: <https://www.academiceffectiveness.gatech.edu/resources/cios/>
 - **Please complete.** I take them seriously and use them to improve my methods
 - Should only take 10 to 15 minutes, tops.
- **Surveys are anonymous**, and instructors do not see survey results until 5 days after grades are due. Also, please address comments directly to your instructors. Comments for your regular instructors are shared only with those instructors (not with school chairs or other administrators, as they see the numerical results only), while **comments for your TAs are shared with both the TA and their supervising instructor.**

| Eval | Course Prefix | Course Number | Sec | Type | Name | Begin | End | Not Resp. | Resp. | Tot. |
|-------------------------|---------------|---------------|-----|------|---------|-------|-------|-----------|-------|------|
| Preview | CS | 4731 | A | A | Game AI | 11-25 | 12-15 | 88 | 0 | 88 |
| Preview | CS | 7632 | A | A | Game AI | 11-25 | 12-15 | 53 | 0 | 53 |