Appendix C. Artificial Intelligence in Video Games

Table 1 contains a list of game intelligence systems and techniques, sorted in release year. Note that the following list of games is by no means exhaustive to cover all the type of artificial games. Moreover, the selection mainly includes the games with virtual world features, i.e., players incarnated by avatars. Thus, artificial intelligent techniques in other genres, such as real-time strategy and board game, are not included.

Figure 1 shows the milestones of game AI innovation in the industry within the last 40 decades. The most rapid development is the game NPCs which appear to have believable or human-like characteristics in interaction. In the 1970s, NPCs only performed with simple stored patterns. In the 1980s, NPCs had different personality traits (e.g., Pac-Man) and primitive artificial behaviors (e.g., Metal Gear). In the 1990s, NPCs had autonomous behaviors by applying finite state machine (FSM), Monte Carlo Search Tree (MCST), and neural network. In the 2000s, NPCs can perform human-like task decision making with decision-tree, behavior-tree, hierarchical task network, the belief-desire-intention model, and the goal-oriented action planning (GOAP) architecture. Note that some late techniques, such as Radiant AI, integrated the early ones to provide comprehensive solutions. In the recent decade, NPCs are more adaptive to the environment (e.g., the adaptive behavior in Alien: Isolation), smarter in collaboration (e.g., the companion AI in The Last of us), and more vivid in animation (e.g., the realistic crowd locomotion in Hitman).

The game AI in procedural content generation (PCG) can automatically generate game content to provide players diverse gaming experience without increasing the cost in game design and development. The evolution of procedural content generation (PCG) started from the late 1980s, when PCG can only create simple dungeon maps (e.g., Rogue). With the development of the PCG technique (Hendrikx et al., 2013), virtual worlds can autonomously create a complex world system (e.g. Eve Online), many 3D models (e.g., .kkrieger), and a full scenario with random quests (e.g., Diablo II). More interestingly, Silent Hill can use psychological profiling to adjust the game based on the player's personality determined in play. Eventually in No Man’s Sky, everything of the world is created on-the-fly.

Moreover, game AI can also develop game plots for augmenting users’ dynamic game experience. For instance, the computational narrative techniques can achieve interactive storytelling (e.g., Façade) and utilize multiple virtual cameras in an interactive drama (e.g., Heavy Rain) to augment the immersion experience.

Table 1. List of game intelligence systems or techniques.

Game	Year	Genre	System or technique	Description
Space Invaders[1]	1978	Arcade	Stored pattern	Simulating random movements of the aliens that were actually pre-programmed into the game.
Pac-Man[1]	1980	Arcade	Complex Stored pattern	Different colorful enemies exhibit different personality traits
Rogue[17]	1980	Role-playing	PCG on game space	Provide changing play experiment with dynamic game environment generation.

Metal Gear[3]	1987	Action-adventure	Artificial behavior	NPCs are capable of hearing player movement, noticing gunshots, and behaving based on a lot more variables
Mortal Kombat[1]	1992	Fighting	FSM	Prompt enemy action in each single state
Civilization II[4,5]	1996	Turn-based strategy	MCST	To create a competitive opponent
Creatures[11]	1996	Life Simulation	Artificial life model, Neural network	Simulate real life functions, such a mutation and decision making
Half-Life[3]	1998	First-person shooter	FSM, Squad AI	Enable members of a squad of NPCs to coordinate their behaviors, allowing them to see their colleagues and notice if they are killed through sense simulation
The Sims[1]	2000	Simulation	Artificial life, Terrain analysis	Create realistic, lifelike behaviors in game characters with rule-based system, genetic algorithms, flocking algorithms, and decision-making hierarchy; Make the pathfinding problem more flexible and location-based
Halo[3]	2001	First-person shooter	Decision-tree, Squad AI	Decision-tree creates dynamic enemy behaviors, such as cover-based behavior
Black and White[6]	2001	Simulation	Belief-desire-intention model, Decision tree, Perceptron neural network	For sophisticate task selection
EVE Online[17]	2003	MMORPG	PCG on game system	Create the entire solar system
.kkrieger[17]	2004	First-person shooter	PCG on game bits	Create texture, meshes, and sounds
Halo 2[7]	2004	First-person shooter	Behavior tree	It is a hierarchical finite state machine to create complex tasks for control in different granularity
F.E.A.R.[3]	2005	First-person shooter	GOAP	The architecture is for NPC to extremely varied behavior that was perceived as intelligent, and to adapt to new situations.
Façade[15]	2005	Interactive drama	Computational narrative	Through artificial intelligence to bring interactive storytelling experience
Diablo II[17]	2008	Action-adventure	PCG on game scenarios	Create quests
GTA4[3]	2008	Action-adventure	Emotion-response, Squad AI, Decision-tree	Emotion-response enable NPCs to react in a realistic way
Left 4 Dead[13,16]	2008	First-person shooter	AI Director, Pathfinding	A PCG mechanism to provide players a dynamic experience based on their performance; A* algorithm is applied to move NPCs to a certain location
Killzone 2[8]	2009	First-person shooter	HTN planning, Squad AI	HTN planning is based on visual perception to create believable NPCs,
Silent Hill: Shattered Memories[9]	2009	Survival horror	Psychological profiling	A PCG mechanism to adjust gameplay elements based on the player's personality determined by the interaction with the game

Heavy Rain[15]	2010	Interactive drama	Computational narrative, Virtual camera	Improve immersion in storytelling
The Elder Scrolls V: Skyrim[14]	2011	Open world	Radiant AI	Allow NPCs to dynamically react to and interact with the world
Hitman: Absolution[10]	2012	Action-adventure	Reinforcement learning	For animation to generate realistic locomotion for NPC crowd
République[12]	2012	Action-adventure	Tactical Pathfinding, GOAP, Point of interest (POI)	POI allows NPCs to randomly utilize the nearby items to create great variety behaviors
GTA5[1,2]	2013	Action-adventure	Pathfinding, Artificial life, NPC-to-NPC interaction, Computer vision	Computer vision is applied to learn distance to stop signs in a race
The Last of Us[3]	2013	Action-adventure	Companion AI	For NPC to coordinate with player character.
Alien: Isolation	2014	Survival horror	Adaptive behavior	NPC behavior is adapted with each decision made by players
Forza Horizon 2[3]	2014	Open world	Drivatar system	Use Neural networks to learn about driving of each player of the game for emulation
Metal Gear Solid 5[1]	2015	Open world	Smart opponent	NPC can hunt players, improve health levels, reload ammo or seek cover during battle
No Man's Sky[18]	2016	Open world	Extreme PCG	Everything in the world is procedurally-generated

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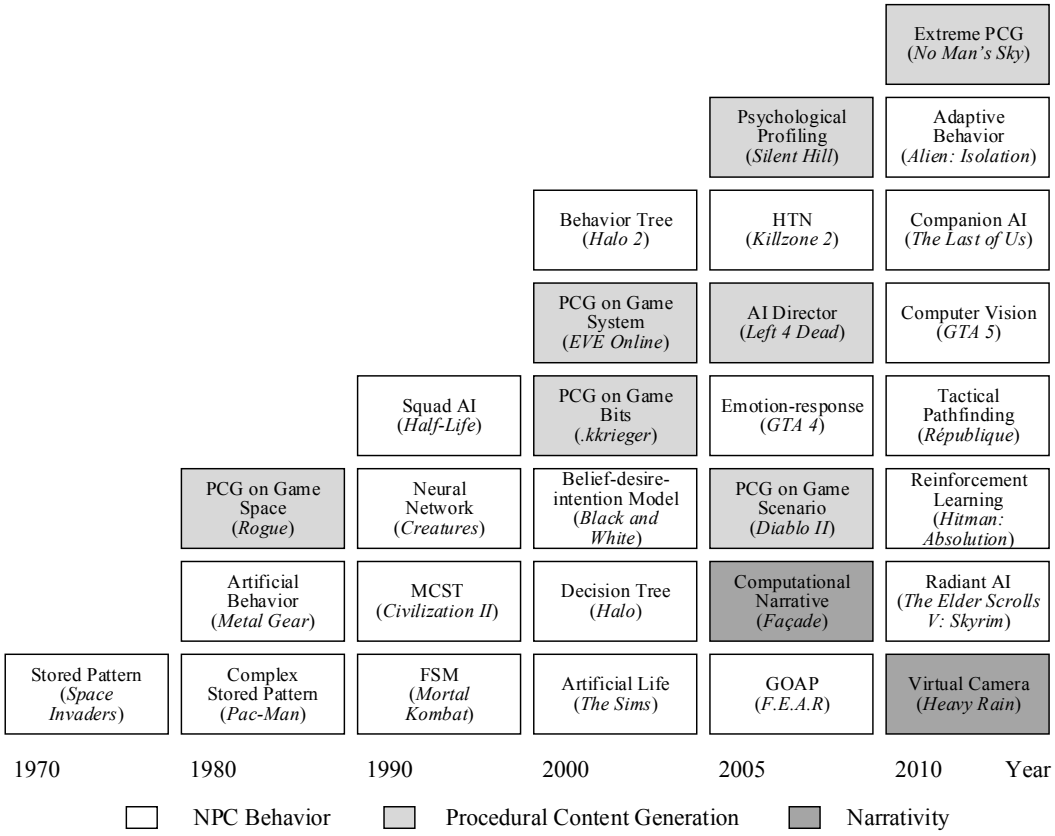

Figure 1. Milestones of game intelligence. See the complete list in the supplemental material (B. Shen, Tan, et al., 2019).