Evaluating dynamic difficulty adaptivity in shoot'em up games

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Summary

Summary of this research:

- Study of dynamic difficulty adaptivity and player modelling.
- Study of previous work (industry and academia).
- Implementation of a dynamic difficulty adaptive system for shoot'em up games based on Charles and Black's framework (Charles et al., 2005).
- Tests with players (casual and hardcore): 35 subjects.
- Evaluation of the dynamic difficulty adaptivity system from the perspective of flow theory (Csikszentmihalyi, 1990) and the model of core elements of the game experience (CEGE) (Cálvillo-Gámez et al., 2010).

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Previous work

- First documented use of dynamic adaptivity in games: Zanac (Compile, 1986).
- Dynamic adaptive system framework (Charles and Black, 2004; Charles et al., 2005).
- Player performance-driven powerups in FPS (Hunicke and Chapman, 2004; Hunicke, 2005).
- Adaptive pong for two players (Ibañez and Delgado-Mata, 2011).
- Infinite adaptive Mario (Weber, 2010b; Weber, 2010a; Weber, 2010c).
- Dynamic scripting (Spronck et al., 2006).
- Fuzzy rules, fuzzy state machines, genetic algorithms (Demasi and Cruz, 2003a; Demasi and Cruz, 2003c; Demasi and Cruz, 2003b).
- M5P classifier (Machado et al., 2011a).
- Player modelling support for adapting the game (Yannakakis and Maragoudakis, 2005; Yannakakis, 2008; Yannakakis and Hallam, 2008).

Commercial games

Some examples:

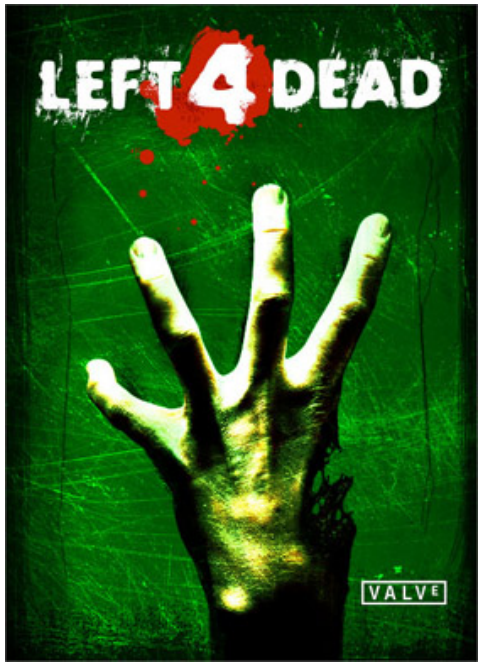

Figure: Left4Dead. Source: (Valve Corporation, 2008).

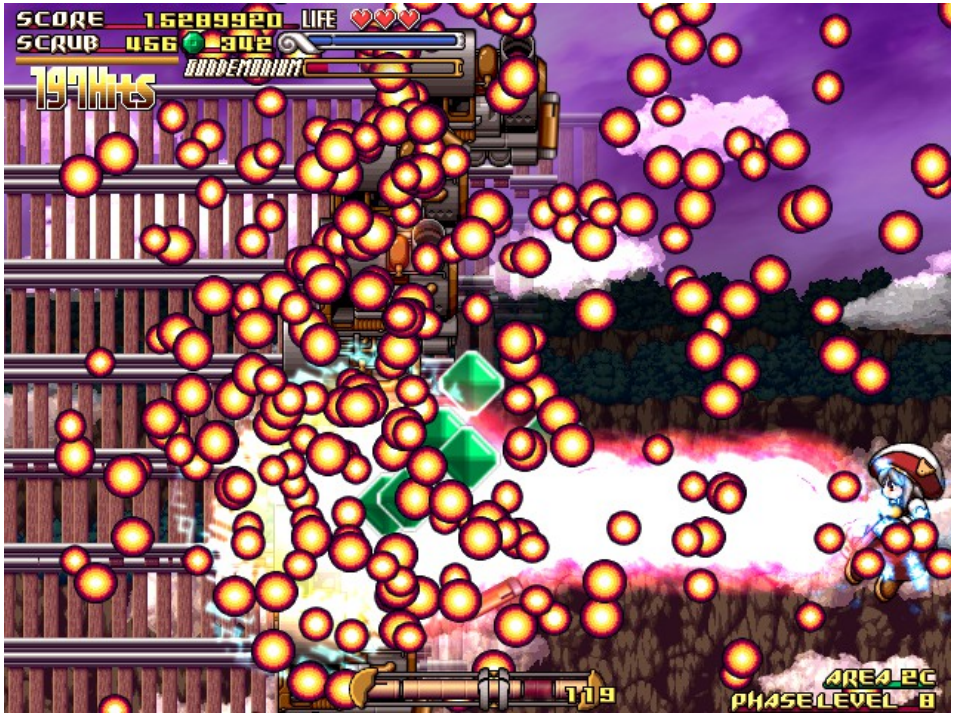

Figure: GundeadliGne. Source: (Android, 2010).

Others include: Mario Kart 64 (Nintendo EAD, 1996), Max Payne (Entertainment, 2001).

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Game

Game - Juul (2003)'s definition

- Formal system of rules
- Player exerts effort working with this rule set
- Player is emotionally linked to the result

Game - Additional definitions

- **Fun:** When players understand and dominate the challenges (Koster, 2004)
- **Boredom:** Lack of new patterns (or challenges) or difficulty too high or too low (Koster, 2004)
- **Anti-Buddhism:** "Die and remember", players sacrifice lives for the knowledge gained in such way (Poole, 2007; Xavier, 2010)
- **Difficulty:** Challenge-Skill relationship

Flow

(Csikszentmihalyi, 1990)

> *"...a feeling of complete and energized focus in an activity, with a high level of enjoyment and fulfillment." (Schell, 2011).*

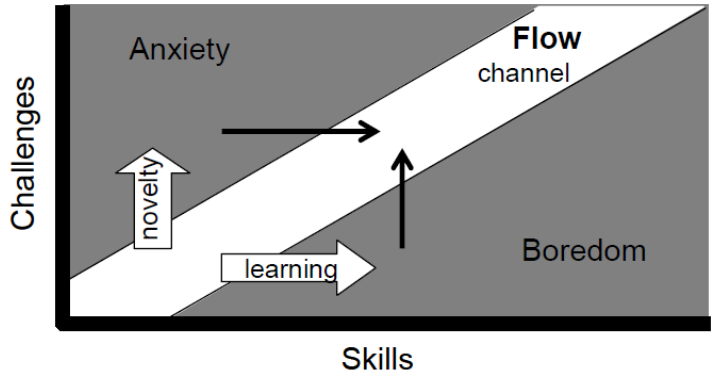

Figure: Flow channel. Extracted from (Cowley et al., 2008).

Elements of flow

- Clear objectives
- No distractions
- Direct feedback
- Continuous challenge

Individual

- Autotelic personality (seeks flow state)
- Skills proportional to the challenge

Player

Defining the player

- Interacts with the game
- Seeks fun (Huizinga, 2010; Koster, 2004)

Classifying the player

- Demographic classifications (Schell, 2011, pp. 99–102), (Novak, 2011)
- Psycho-types (Myers-Briggs, Bartle (1996), LeBlanc etc.)
- Casual X Hardcore

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Dynamic Difficulty Adaptivity

What for?

Personalize the game experience by a dynamic factor such as player's skills. (Lopes and Bidarra, 2011).

Characteristics

- Online X Offline
- Requirements: (Andrade et al., 2006)
  - Identify and adapt to player skill
  - Perceive and register player evolution
  - Changes should be discrete and credible

Player Modelling

What is it?

Technique to infer higher order attributes from the player using game-play data so the player can be classified.

Taxonomy proposals

- (Machado et al., 2011b; Machado et al., 2011c).
- (Smith et al., 2011).

How to do it?

- Fuzzy models (Demasi and Cruz, 2003a).
- Supervised learning (Missura and Gärtner, 2009).
- Neural networks (Yannakakis and Maragoudakis, 2005; Pedersen et al., 2009; Yannakakis, 2008; Yannakakis and Hallam, 2008).
- Charles and Black's framework (Charles and Black, 2004; Charles et al., 2005).

Charles and Black's framework

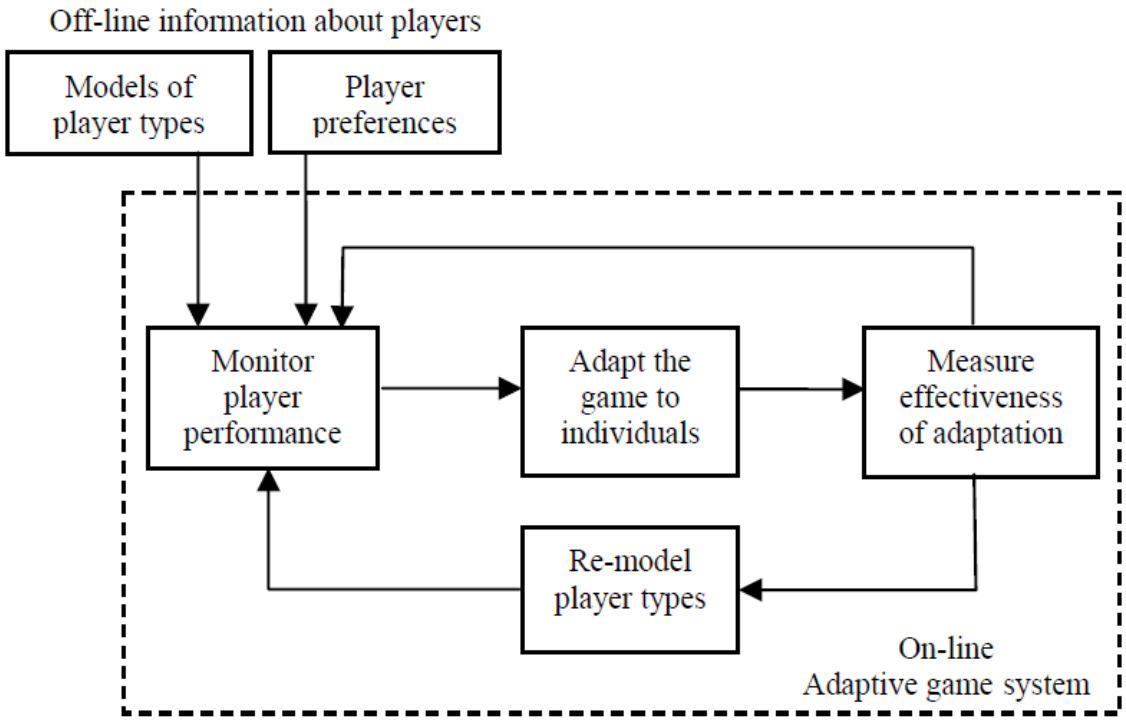

Figure: Charles and Black's player modelling adaptive framework. Source: (Charles and Black, 2004).

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Methodology

Game developed

Figure: Adaptive Shooter

Methodology

- Shoot'em up game
- Adaptive version x Non-adaptive version
- Implementation of (Charles et al., 2005)'s framework.
- 3 lives
- Initial setup for both versions: Easy, Medium, Hard
- Enemies comes in waves (adaptivity occurs between waves in the adaptive version)
- Enemies variables controlled by difficulty:

$$V = \{speed, shotDelay, halfRange\} \quad (1)$$

- C++, Lua, ClanLib
- Test group: 35 players

Adaptive algorithm

- Based on (Charles and Black, 2004)'s framework
- Adaptive method proposed by (Houlette, 2004).

Table: Player models implemented

	Easy		Medium		Hard	
	Min	Max	Min	Max	Min	Max
Accuracy	0.0	0.3	0.3	0.6	0.6	1.0
Lives variation	0.6	1.0	0.3	0.6	0.0	0.3
Enemies per wave	0.0	0.3	0.3	0.6	0.6	1.0
Enemies total	0.0	0.3	0.3	0.6	0.6	1.0
Total	0.6	1.9	1.2	2.4	1.8	3.3

Adaptive algorithm

Algorithm 1 Adaptive algorithm

$\alpha \leftarrow$ learningRate
$type_0 \leftarrow$ initial type informed by the player
$c_i \leftarrow \frac{(c_{i,min}^{type_0} + c_{i,max}^{type_0})}{2}$ {i.e., the average of the standard performance $type_0$ for each trait c_i.}
$V \leftarrow$ initial state of behaviour variables
for all *waves* **do**
  $c_{i,obs}$ is the perceived trait value i
  $c_i \leftarrow c_i + \alpha \times (c_{i,obs} + c_i)$ {i.e., updates each trait by LMS.}
  $performance \leftarrow \sum_{i=1}^{n} c_i$
  if $performance \in [MIN^{type}, MAX^{type}]$ **then**
    $newModel \leftarrow type$
  else if $currentModel \neq newModel$ **then**
    Remodel player:
    $V \leftarrow adjust(currentModel)$
  else
    Maintains current model
  end if
  Store wave's statistics
end for

Adaptive system

Algorithm 2 function AIManager.update( )

```
result ← 0
for playerModelIterator ← playerModels.begin() to playerModels.end()
do
  result ← currentObservedModel.(playerModelIterator)
  if result < 0 then
    continue
  else if result = 0 then
    currentReferenceModel ← playerModelIterator
  else
    result ← currentReferenceModel.compare
    (playerModelIterator)
    if result < 0 then
      currentReferenceModel ← playerModelIterator
    end if
  end if
end for
currentObservedModel.setName(currentReferenceModel.getName())
updateAgents()
```

Adaptive system

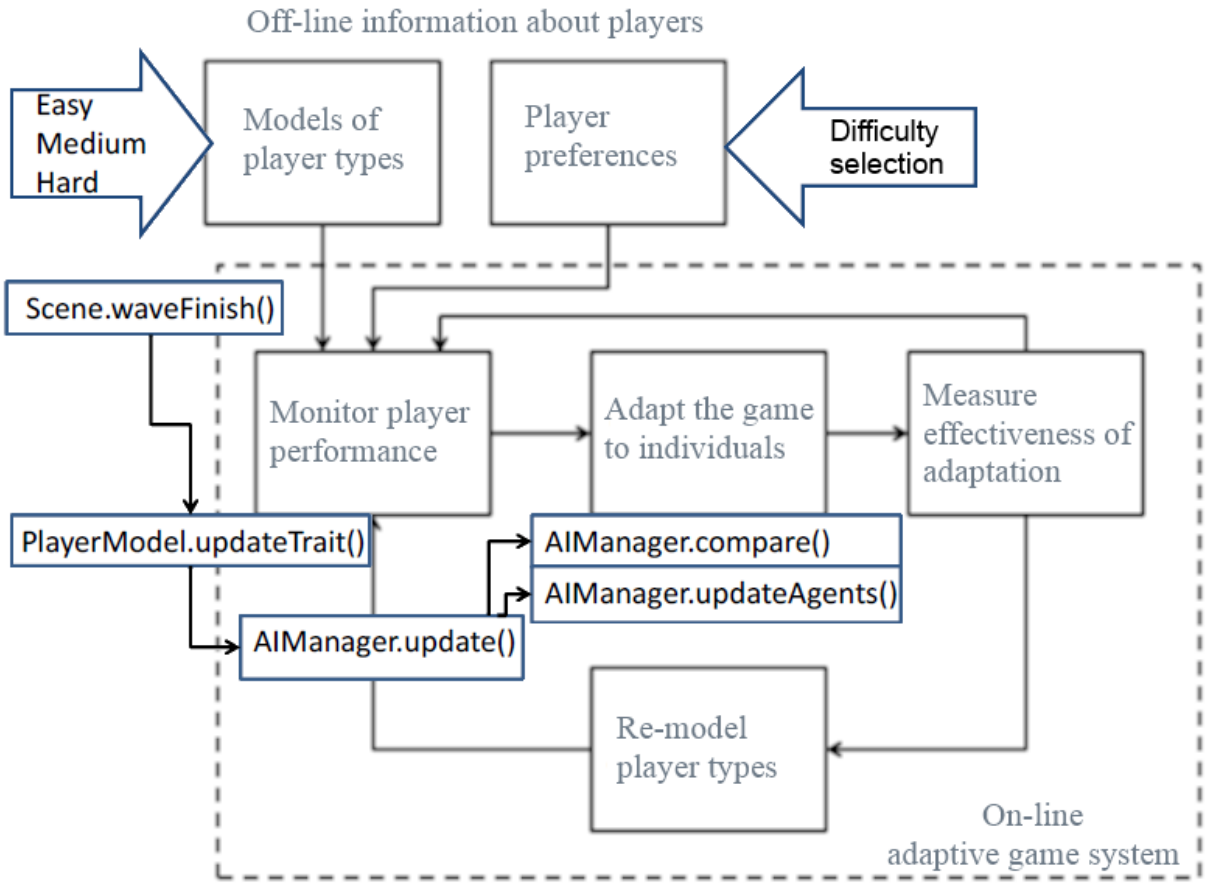

Figure: Superposition of our system to Charles and Black (2004)'s framework.

Evaluating with player testing

- Population: 35 players
- Following Fullerton et al. (2008)'s recommendations.
- Players tested both versions of the game, not knowing which version was being played each time. First version was exchanged between players to avoid learning bias.
- Three steps:
  - Pre-test questionnaire: player self-evaluates as casual or hardcore.
  - Versions playtest followed each by a post-game experience questionnaire.
  - Interview to assess subjective and qualitative data, following Hoonhout (2008)'s recommendation.
- Post-game experience questionnaire used the CEGE framework (Cálvillo-Gámez, 2009; Cálvillo-Gámez et al., 2010) for evaluation of game experience.

Core elements of game experience (CEGE) framework

- Used to detect which version gave the player the best experience in terms of those elements
- 38-item questionnaire in a 7-point Likert scale that evaluates to 2 scales

Table: Relationship between questionnaire questions and game experience factors, adapted from Cálvillo-Gámez et al., 2010, p. 65.

Items	Factor
1, 4, 5	Enjoyment
2, 3	Frustration
6–38	Core Elements of Game Experience
6–25, 38	Puppetry
26–37	Videogame
6–12, 25, 28	Control
13–18	Facilitators
19–25	Ownership
26–31	Environment
32–37	Game-play

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Results

Table: Participants summary - Sex, Classification

Participants					
Total	Male	Female	Casual	Hardcore	Non-player
35	16	19	18	16	1
%	46%	54%	51%	46%	3%

- The self-classified non-player was considered casual for the rest of the analysis.
- Analysis considered the players divided between casual and hardcore
- Version 1 refers to the adaptive version of the game.
- Version 2 refers to the non-adaptive version of the game.

Results - Hardcore players

Table: Comparison of CEGE scales for hardcore players

	Comparison of CEGE scales for hardcore players					
		Version 1		Version 2		
	Factors	Sum	Mean	Sum	Mean	Difference %
Scale 1	Enjoyment	281	5,8542	285	5,9375	-1,40%
	Frustration	74	2,3125	85	2,6563	-12,94%
	CEGE	2925	5,5398	2880	5,4545	1,56%
	Puppetry	1775	5,2827	1756	5,2262	1,08%
	Video-game	1150	5,9896	1124	5,8542	2,31%
Scale 2	Control	866	6,0139	859	5,9653	0,81%
	Facilitators	478	4,9792	477	4,9688	0,21%
	Ownership	529	4,7232	511	4,5625	3,52%
	Environment	592	6,1667	566	5,8958	4,59%
	Game-play	558	5,8125	558	5,8125	0,00%

Results - Hardcore players

- The adaptive version had a lower Frustration score than the non-adaptive for hardcore players, although there was no significant difference in Enjoyment.
- The difficulty surge when there was a change in enemies difficulty maintains the hardcore players interest in the game.
- Hardcore player's intrinsic characteristics and autotelic personality explain this result.

Results - Casual players

Table: Comparison of CEGE scales for casual players

	Comparison of CEGE scales for casual players					
		Version 1		Version 2		
	Factors	Sum	Mean	Sum	Mean	Difference %
Scale 1	Enjoyment	311	5,759259	336	6,222222	-7,44%
	Frustration	73	2,027778	68	1,888889	7,35%
	CEGE	3145	5,294613	3157	5,314815	-0,38%
	Puppetry	1869	4,944444	1870	4,94709	-0,05%
	Video-game	1276	5,907407	1287	5,958333	-0,85%
Scale 2	Control	923	5,697531	910	5,617284	1,43%
	Facilitators	483	4,472222	489	4,527778	-1,23%
	Ownership	550	4,365079	546	4,333333	0,73%
	Environment	637	5,898148	650	6,018519	-2,00%
	Game-play	639	5,916667	637	5,898148	0,31%

Results - Casual players

- The adaptive version was more frustrating for casual players. Both low score in Enjoyment and high score in Frustration show this.
- Shoot'em up genre has its peculiarities that may hinder casual players enjoyment.
- The characteristics that make a game enjoyable and interesting for hardcore players are considered too hard and unencouraging for causal players (Fortugno, 2008).

Results - Game ending

- 12 players reached the end of the adaptive version
- 8 players reached the end of the non-adaptive version
- Among the players who finished the game, 7 of 12 (58%) said that they observed a difference in difficulty level although only 3 of the whole 35 (8%) detected actual difficulty changes.

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Conclusion

- Our results support the common-sense idea that hardcore players have a better assimilation of the gaming experience.
- Casual players presented a tendency to prefer the non-adaptive version.

> *"However, it is the rare player who is persistent enough to win the game, mastering all levels. Most players eventually reach a level where they spend so much time in the frustration zone that they give up on the game." Schell, 2011, p. 121.*

Contributions and future work

Contributions

- Implementation and case-study of Charles and Black adaptive framework.
- An efficient implementation of an adaptive shoot'em up game with online learning.
- Evaluation of dynamic difficulty adaptivity with casual and hardcore players, showing that hardcore players experience can benefit from the use of dynamic difficulty adaptivity

Future work

- Test with other game genres. Shoot'em up is a niche game genre and further research should consider other game genres and their idiosyncrasies in implementing a dynamic difficulty adaptive system.
- Study the possibility of including dynamic adaptivity in interactive storytelling media.

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