10 Years of the PCG workshop: Past and Future Trends

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Motivation

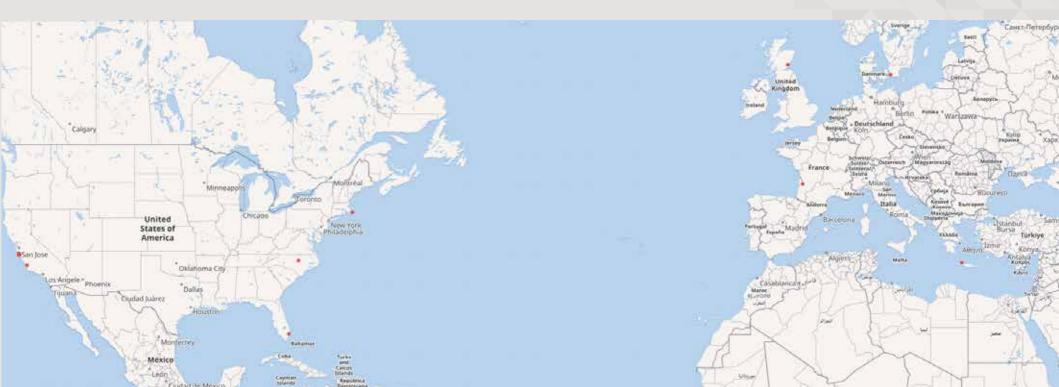
- This is the 11th PCG workshop!
- Survey the paper corpus of the first 10 workshops, identifying algorithms, game genres and other trends
- 95 papers surveyed over 10 years



Published Papers

A Short History

- ь FDG 2010: 1st workshop
 - organized by R. Bidarra, I. Bogost, I. Parberry, K. O.
 Stanley, J. Togelius, J. Whitehead, R. M. Young
- 6 instances in USA, 4 instances in Europe



A Short History

184 distinct authors (avg 2.9 authors per paper)



A Short History

80% of papers have keywords

GAMIFICATION PROCEDURAL RHETORIC PSEUDO-RANDOM NUMBER GENERATION CELLULAR AUTOMATA GAME TERRAIN GENERATIVE DESIGN SEARCH-BASED PROCEDURAL CONTENT GENERATION GRAPH DATA MINING GENERATIVETY VOXELS GAME BALANCING AUTOMATED GAME DESIGN PCG-BASED GAME DESIGN GAME MECHANICS CHAOS PLANNING ADAPTIVE GAMES EVOLUTIONARY COMPUTATION SHOOTER GAMES AUTOMATED PLAYTESTING DESIGN TOOLS PROCEDURAL MODELING ANSWER SET PROGRAMMING PHILOSOPHY OF SCIENCE GRAPH GRAMMARS QUEST LEARNING 2D PLATFORMERSGAME LEVEL GENERATION ARTIFICIAL INTELLIGENCE INFINITE WORLD GENERATION INTRACTABILITY TRAINING CHARACTER. PROBABILISTIC MODELS URBAN MODELING DESIGN MOTIF MULTI-AGENT SYSTEMS POPULATION GENERATION USER INTERFACE TAROT SHAPE GRAMMARS NARRATIVE GENERATION PROCEDURAL ANIMATION A-STAR SEARCH JAVA RATIVE METHODS GAME ANALYSIS STUDIES. ADAPTIVE GAME WORLDS LEVEL PATTERNS CAPTCHA NOISE FUNCTIONS SIMULATION ROLE-PLAYING GAMES CONTEXT-SENSITIVE GENERATION VIDEO GAR GAMES DYNAMIC DIFFICULTY ADJUSTMENT NODE-BASED DESIGN PERFECT MAZE BALANCING AUTHORIAL BURDEN PROCEDURAL CITY GENERAT UAGE GENERATIONGRAPH ISOMORPHISM OPTIMIZATION CARD GAMES ERASURE POETRY GENERATION ADVENTURE GAMES HISTORY GAME DESIGN ROLE-PLAYING GAME MIXED-INITIATIVE INTERFACE FL-SYSTEMS USER-DEFINED PATHS COLLABORATIVE STORYTELLING PUZZLES GRAPH REWRITE RULES FEASIBLE INFEASIBLE CONSTRAINT SOLVING EVOLUTIONARY ALGORITHMS DESIGN PATTERNS EXPRESSIVE DANCE EVENESSION PROCEDURAL TERRAIN GENERATION PLAYER CREATIVITY PARAMETRIC ISOVIST GENERATIVE ALGORITHMS USER ABANDONMENT₃D CONTENT GENERATION EXPRESSIVE RANGE ANALYSIS GAME DEVELOPMENT GIS NPC SUPER MARIO BROS DOMAIN-SPECIFC LANGUAGES DEEP LEARNING COMPUTER GAMES ROAD NETWORK GENERATION GAME GENERATION RPG OUALITY MANUAL MODELLING VIRTUAL URBAN ENVIRONMENTS VIRTUAL CITY GENERATION LESSONS LEARNED CONEAT SEMAN'I MINECRAFT 3D WIIHABILITATION STOCHASTIC GRAPH GRAMMARS ACTION ADVENTURE GAMES MAZE GENERATION NATURAL JAPANESE PROCEDURAL FILTERS QUALITATIVE PROCEDURAL GENERATION IPUTATIONAL MODELING OF LANGUAGE SCENARIO GENERATION PUZZLE GAMES RELATIONSHIPS OBJECT INTERACTION PATCH-BASED NETWORK GENERATION SEARCH BASED LEVEL GENERATION STORY RECOGNITION BOARD GAMES LEVEL DESIGN PHYSICS-BASED INTERACTION DESIGN AI GAME DESIGN ASSISTED TOOL SIMULATION-BASED APPROACHES TEXTURE SYNTHESIS COMPETITION PROLOG RESTART POLICY GENERATIVE PIPELINES CHALLENGE BALANCING CLOSE READING MYTH URAL LEVEL GENERATION GRAPH SUBSETS DATA REPRESENTATION PROCED EVALUATION METHODS EXPLORATION REAL-TIME GRAPH COARSENING IMPLICIT USER FEEDBACK AUTOMATED GAME PLAYING PERSONALISATION READING MACHINE LEARNING MMORPG VIRTUAL TERRAIN FIRST-PERSON SHOOTERS CONSTRUCTIVE METHODS NON-REPETITIVE CORPUS REPRESENTATION COMMONSENSE KNOWLEDGE DECLARATIVE MODELING OUOTIENT GRAPH LEVELS SURROGATE MODEL IMMERSIVE ENVIRONMENT LUTIONARY ALGORITHM PLAYER MODELING ETHICS RESPONSIVE ASSISTIVE DESIGN STORY GAMES GRAPH-CONNECTIVITY PHILOSOPHY OF PROCEDURAL CONTENT GENERATION CALACTIC ARMS RACE. CO.CREATIVITY TABLETOP GAMESGRAPH PARTITIONINGCOMPUTER GENERATED DECORATIVE PATTERNS GAME DESIGN THEORY GAME WORLDS

Survey #1: Types of Content Generated

Levels/worlds (49 papers)



Vectorization of Gridded Urban Land Use Data by C. Sexton and B. Watson (2010) Mobile adaptive procedural content generation by R. Lopes, K. Hilf, L. Jayapalan and Rafael Bidarra (2013) Danesh: Helping Bridge The Gap Between Procedural Generators And Their Output by M. Cook, J. Gow and S. Colton (2016) Generative Design in Minecraft (GDMC): Settlement Generation Competition by C. Salge, M. Cerny Green, R. Canaan, J. Togelius (2018) Two-step Constructive Approaches for Dungeon Generation by M. Cerny Green, A. Khalifa, A. Alsoughayer, D. Surana, A. Liapis and J. Togelius (2019)

- Levels/worlds (49 papers)
- Architecture (6 papers)

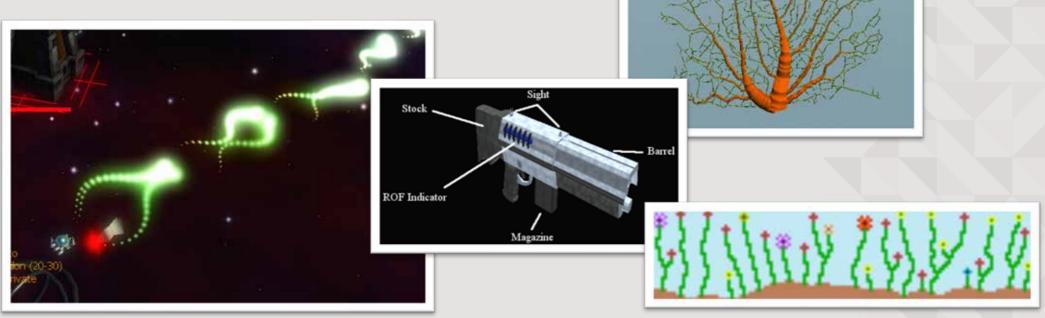


Lessons in User Interface Design in the Procedural City Generation for Games Tool Ürban PAD by L. Barret , C. Vance and G. Michael Youngblood (2011)

Procedural filters for customization of virtual worlds by T. Tutenel, R. van der Linden, M. Kraus, B. Bollen and R. Bidarra (2011) Modeling Urban Environments from Geospatial Data: A Pipeline for Procedural Modeling by D. Jesus, A. Coelho, C. Rebelo and A. Cardoso (2012)

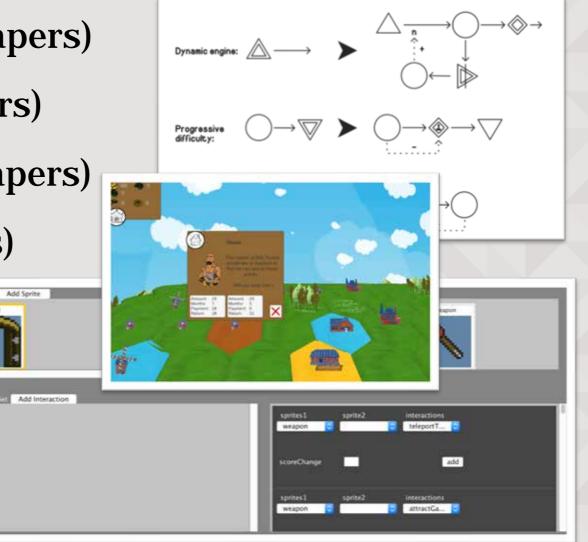
A Generalized Semantic Representation for Procedural Generation of Rooms by J. T. Balint and R. Bidarra (2019)

- Levels/worlds (49 papers)
- Architecture (6 papers)
- L 2D/3D Graphics (8 papers)



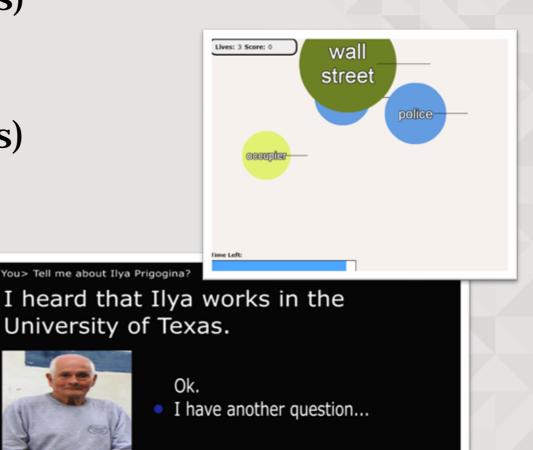
Interactive Genetic Engineering of Evolved Video Game Content by E. J. Hastings and K. O. Stanley (2010) Team Blockhead Wars: Generating FPS Weapons in a Multiplayer Environment by E. McDuffee and A. Pantaleev (2013) A Constructive Approach for the Generation of Underwater Environments by R. Abela, A. Liapis and G. N. Yannakakis (2015) Addressing the Fundamental Tension of PCGML with Discriminative Learning by Isaac Karth and Adam M. Smith (2019)

- Levels/worlds (49 papers)
- Architecture (6 papers)
- 2D/3D Graphics (8 papers)
- Mechanics (8 papers)



Level Design as Model Transformation: A Strategy for Automated Content Generation by J. Dormans (2011) Generating Game Mechanics in a Model Economy: a MoneyMaker Deluxe Case Study by S. Leijnen, P. Brinkkemper and A. Bouwer (2015) Shopping for Game Mechanics by T. Machado, I. Bravi, Z. Wang, A. Nealen and J. Togelius (2016)

- Levels/worlds (49 papers)
- Architecture (6 papers)
- 2D/3D Graphics (8 papers)
- Mechanics (8 papers)
- Games (3 papers)



Game-O-Matic: Generating Videogames that Represent Ideas by M. Treanor, B. Blackford, M. Mateas and I. Bogost (2012) Data Adventures by G. A. B. Barros, A. Liapis and J. Togelius (2015)

Bacl

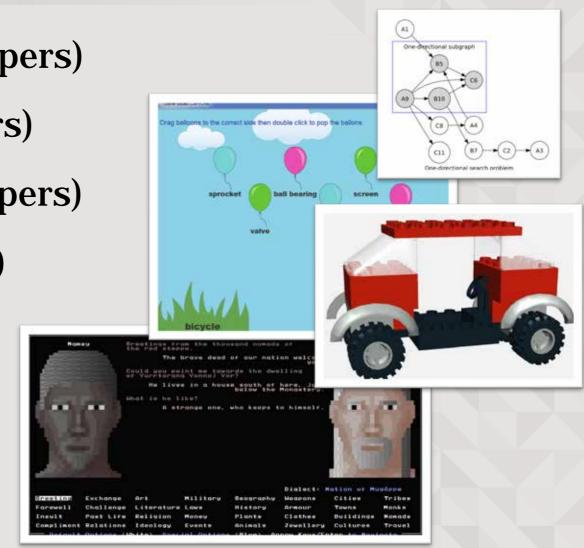
- Levels/worlds (49 papers)
- Architecture (6 papers)
- 2D/3D Graphics (8 papers)
- Mechanics (8 papers)
- Games (3 papers)
- Stories (6 papers)

A sexy student named Oswald expressed concern and wooed a second student named Cassandra. Cassandra allowed Oswald. Cassandra smiled and wooed Oswald. Oswald discouraged Cassandra and blamed her. Oswald smiled and wooed Cassandra. Cassandra allowed Oswald and blushed. Cassandra expressed concern and asked Oswald to date Cassandra. Oswald didn't agree. Cassandra attempted to plan to meet a third student named Nicholas. Nicholas agreed and congrat-



Generating Natural Language Retellings from Prom Week Play Traces by C. Antoun, M. Antoun, J. O. Ryan, B. Samuel, R. Swanson and M. A. Walker (2015) Tarot-Based Narrative Generation by A. Sullivan, M. Palosaari Eladhari and M. Cook (2018)

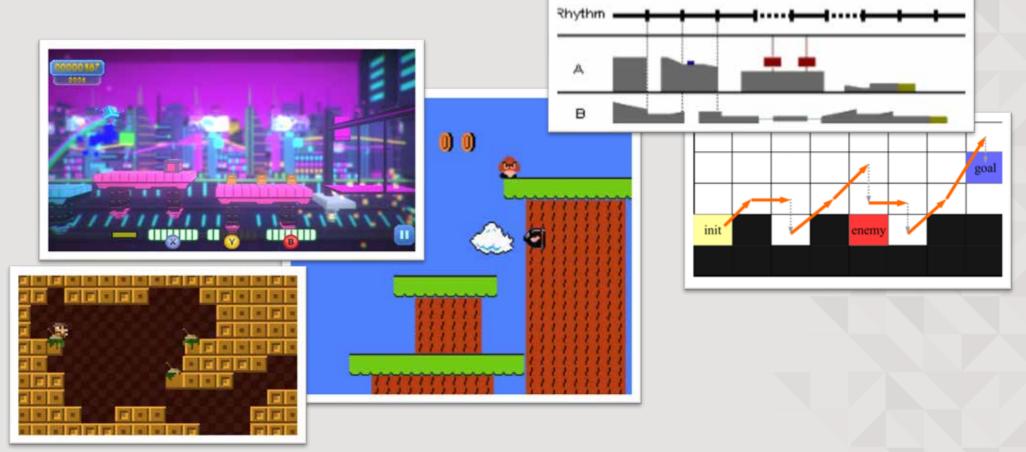
- Levels/worlds (49 papers)
- Architecture (6 papers)
- L 2D/3D Graphics (8 papers)
- Mechanics (8 papers)
- Games (3 papers)
- Stories (6 papers)
- Other (12 papers)



Fast exact graph matching using adjacency matrices by Marlon Etheredge (2012) Automatic Generation of Game-based CAPTCHAs by H. Yu and M. O. Riedl (2015) Design Motifs: A Grammar Based Approach by J. Mazeika and J. Whitehead (2015) Procedural Generation of Linguistics, Dialects, Naming Conventions and Spoken Sentences by M. R Johnson (2016)

Survey #2: Target Game Genres

Platformers (14 papers)



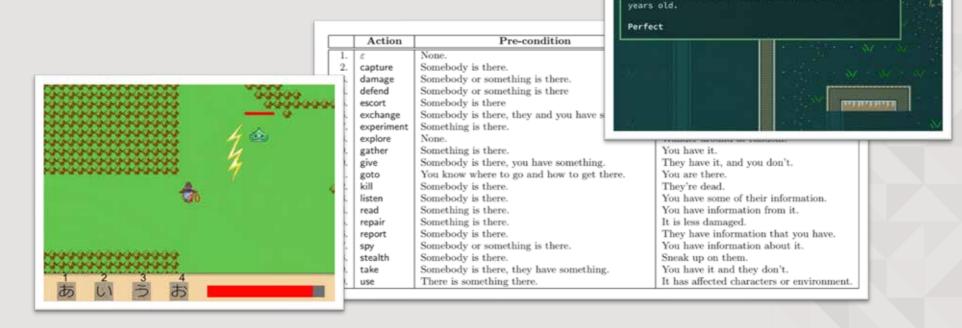
Polymorph: Dynamic Difficulty Adjustment Through Level Generation by M. Jennings-Teats, G. Smith and N. Wardrip-Fruin (2010) Generating and Adapting Game Mechanics by A. Zook and M. O. Riedl (2014) Toward Game Level Generation from Gameplay Videos by M. Guzdial and M. O. Riedl (2015) Towards Procedural Generation As Gameplay: CLAY and Tombs of Tomeria by M. Cook and S. Colton (2016) Scalable Level Generation for 2D Platforming Games by N. Dewsbury, A. Nunn, M. Syrett, J. Tatum and T. Thompson (2016)

- Platformers (14 papers)
- Real-world simulation (13 papers)



Generating Responsive Life-Like Biped Characters by B. Kenwright (2012) Procedural generation of populations for storytelling by B. in het Veld, B. Kybartas, R. Bidarra and J-J Ch. Meyer (2015) A Generalized Semantic Representation for Procedural Generation of Rooms by J. T. Balint and R. Bidarra (2019) TownSim: Agent-based city evolution for naturalistic road network generation by A. Song and J. Whitehead (2019)

- Platformers (14 papers)
- Real-world simulation (13 papers)
- RPGs (12 papers)



shrine to Uumasp II, Mirrorborn

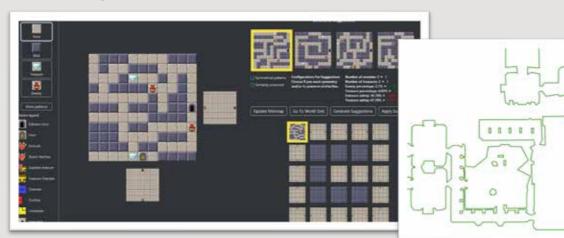
of the ancient sultan Uumasp II:

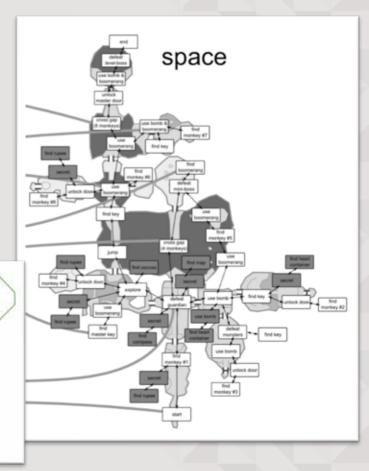
The shrine depicts a significant event from the life

While leading a small army in Forum Province Alep, Uumasp II assassinated the sultan of Qud over an ordinance prohibiting the practice of staining glass. She won and ascended to the crown. She was 6

A Prototype Quest Generator Based on a Structural Analysis of Quests from Four MMORPGs by J. Doran and I. Parberry (2011) Teaching Japanese through Game Mechanics: An exploratory study by C. Olson, D. Kauffman, A. Fowler and F. Khosmood (2015) Subverting Historical Cause & Effect: Generation of Mythic Biographies in Caves of Qud by J. Grinblat and C. B. Bucklew (2017)

- Platformers (14 papers)
- Real-world simulation (13 papers)
- RPGs (12 papers)
- Roguelikes (12 papers)

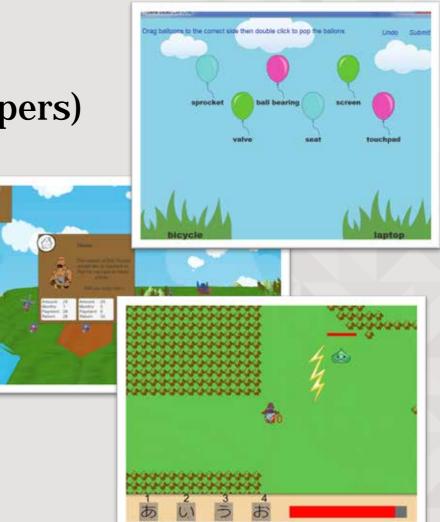




Adventures in Level Design: Generating Missions and Spaces for Action Adventure Games by J. Dormans (2010) Exhaustive Exploration Strategies for NPCs by M. Chowdhury and C. Verbrugge (2016) Fostering Creativity in the Mixed-Initiative Evolutionary Dungeon Designer by A. Alvarez, S. Dahlskog, J. Font, J. Holmberg, C. Nolasco and A. Österman (2018)

- Platformers (14 papers)
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- RPGs (12 papers)
- Roguelikes (12 papers)
- Serious games (6 papers)

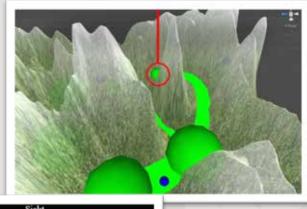


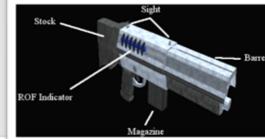


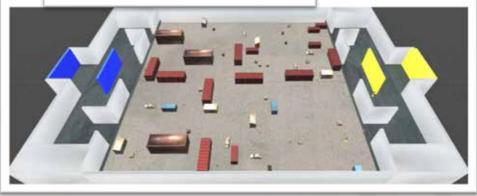
Towards Procedural Level Generation for Rehabilitation by D. Dimovska, P. Jarnfelt, S. Selvig and G. N. Yannakakis (2010) Automatic Generation of Game-based CAPTCHAs by H. Yu and M. O. Riedl (2015)

Teaching Japanese through Game Mechanics: An exploratory study by C. Olson, D. Kauffman, A. Fowler and F. Khosmood (2015) Generating Game Mechanics in a Model Economy: a MoneyMaker Deluxe Case Study by S. Leijnen, P. Brinkkemper and A. Bouwer (2015)

- Platformers (14 papers)
- Real-world simulation (13 papers)
- RPGs (12 papers)
- Roguelikes (12 papers)
- Serious games (6 papers)
- Shooters (6 papers)

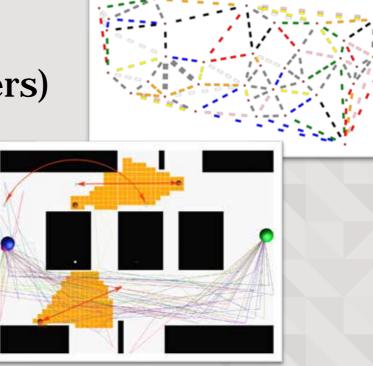






Team Blockhead Wars: Generating FPS Weapons in a Multiplayer Environment by E. McDuffee and A. Pantaleev (2013) Identifying Attributes for Characterizing Game Area Types in Virtual Terrain by A. Pech, P. Hingston, M. Masek and C.-P. Lam (2016) Learning the Paterns of Balance in a Multi-Player Shooter Game by D. Karavolos, A. Liapis and Georgios Yannakakis (2017)

- Platformers (14 papers)
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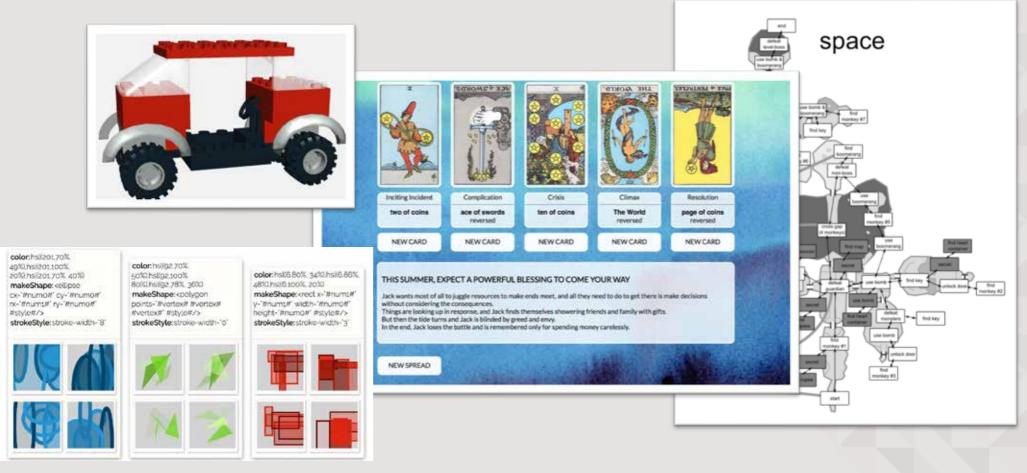


Other: boardgames, strategy, mazes, stealth...

Procedural Guard Placement for Stealth Games by Qihan Xu and Jonathan Tremblay and Clark Verbrugge (2014) Evolving Maps and Decks for Ticket to Ride by Fernando de Mesentier Silva and Scott Lee and Julian Togelius and Andy Nealen (2018)

Survey #3: Algorithmic Approaches

Grammars (15 papers)

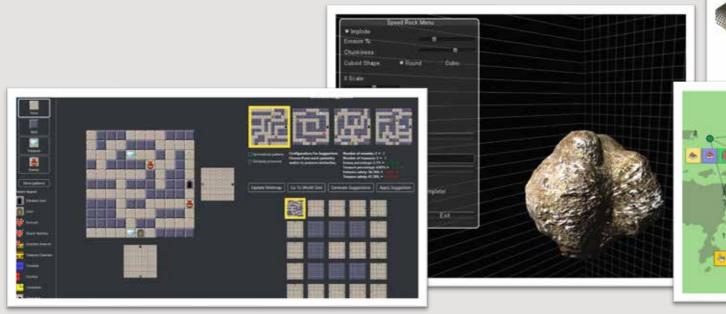


Adventures in Level Design: Generating Missions and Spaces for Action Adventure Games by J. Dormans (2010) Do You Like This Art I Made You: Introducing Techne, A Creative Artbot Commune by J. Pagnutti, K. Compton and J. Whitehead (2016) Design Motifs: A Grammar Based Approach by J. Mazeika and J. Whitehead (2015) Tarot-Based Narrative Generation by A. Sullivan, M. Palosaari Eladhari and M. Cook (2018)

- Grammars (15 papers)
- Constructive methods (14 papers)

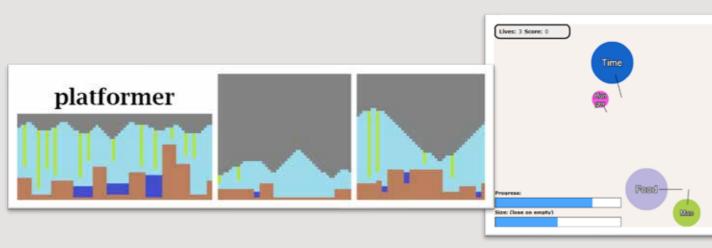
The Use of Functional L-Systems for Scenario Generation in Serious Games by G.A. Martin C.E. Hughes, S. Schatz and D. Nicholson (2010) Cellular automata for real-

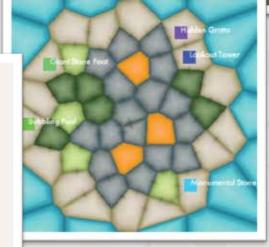
- Grammars (15 papers)
- Constructive methods (14 papers)
- Artificial evolution (14 papers)



Towards multiobjective procedural map generation by J. Togelius, M. Preuss and G. N. Yannakakis (2010) SpeedRock: procedural rocks through grammars and evolution by I. M. Dart, G. De Rossi and J. Togelius (2011) Procedural generation of populations for storytelling by B. in het Veld, B. Kybartas, R. Bidarra and J-J Ch. Meyer (2015) Fostering Creativity in the Mixed-Initiative Evolutionary Dungeon Designer by A. Alvarez, S. Dahlskog, J. Font, J. Holmberg, C. Nolasco and A. Österman (2018)

- Grammars (15 papers)
- Constructive methods (14 papers)
- Artificial evolution (14 papers)
- Declarative programming (13 papers)





Integrating procedural generation and manual editing of virtual worlds by R. Smelik, T. Tutenel, K. Jan de Kraker and R. Bidarra (2010) Game-O-Matic: Generating Videogames that Represent Ideas by M. Treanor and B. Blackford and M. Mateas and I. Bogost (2012) Anza Island: Novel Gameplay Using ASP by K. Compton, A. Smith and M. Mateas (2012) WaveFunctionCollapse is Constraint Solving in the Wild by I. Karth and A. M. Smith (2017)



- Grammars (15 papers)
- Constructive methods (14 papers)
- Artificial evolution (14 papers)
- Declarative programming (13 papers)
- Machine learning (7 papers)



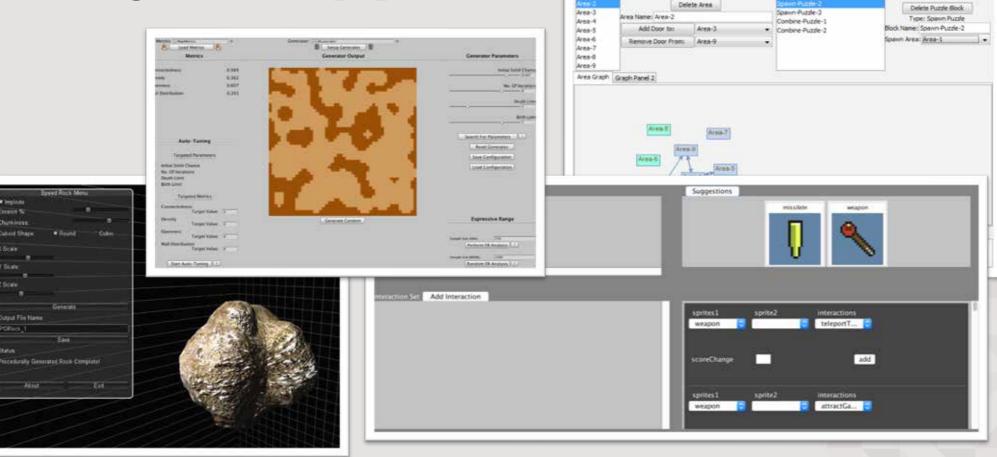


Towards Challenge Balancing for Personalised Game Spaces by S. Bakkes and S. Whiteson (2014) Automatically Categorizing Procedurally Generated Content for Collecting Games by S. Risi, J. Lehman, D. B. D'Ambrosio and K. O. Stanley (2014)

Learning the Patterns of Balance in a Multi-Player Shooter Game by D. Karavolos, A. Liapis and Georgios Yannakakis (2017) Addressing the Fundamental Tension of PCGML with Discriminative Learning by I. Karth and A. M. Smith (2019)

Survey #4: Other Facets

Design tools (19 papers)



A Puzzle-Dice Puzzle Editor

Add Area

Acea-1

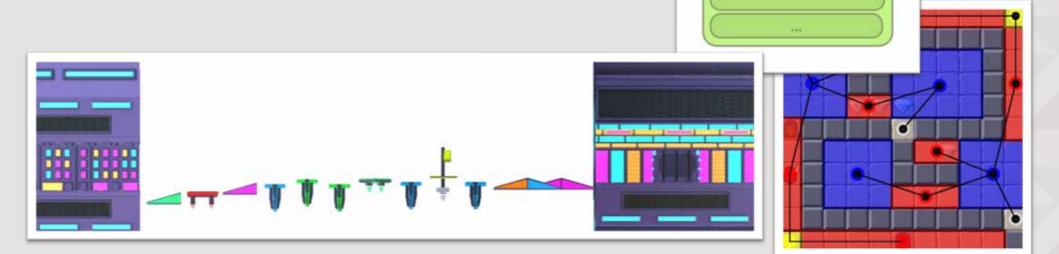
File (TODO) Edit (TODO) Database (TODO) HELP (TODO)

Add Combine Puzzle

Smann-Purnle-1

SpeedRock: procedural rocks through grammars and evolution by I. M. Dart, G. De Rossi and J. Togelius (2011) Procedural Generation of Narrative Puzzles in Adventure Games: The Puzzle-Dice System by C. Fernández-Vara and A. Thomson (2012) Shopping for Game Mechanics by T. Machado, I. Bravi, Z. Wang, A. Nealen and J. Togelius (2016) Danesh: Helping Bridge The Gap Between Procedural Generators And Their Output by M. Cook, J. Gow and S. Colton (2016)

- Design tools (19 papers)
- Design patterns (7 papers)



Micro-Rhetoric

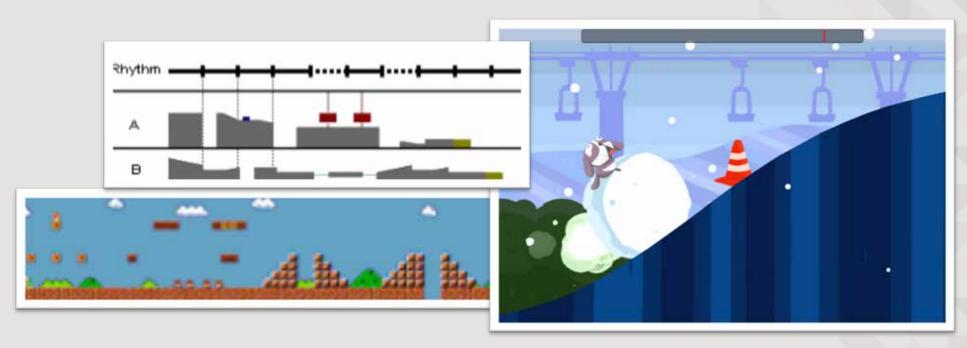
verb

specific id

Component Assignment owner target component parameters

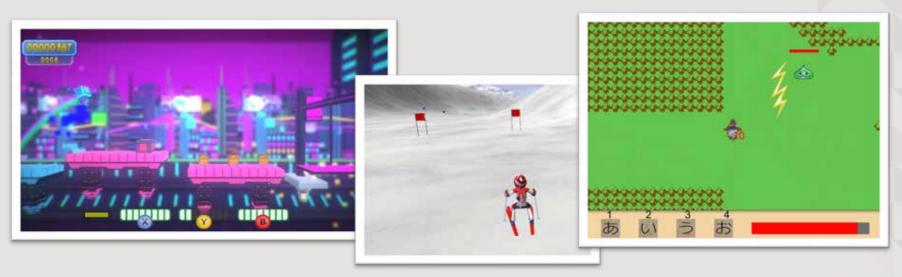
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- Design tools (19 papers)
- Design patterns (7 papers)
- Player modeling (5 papers)



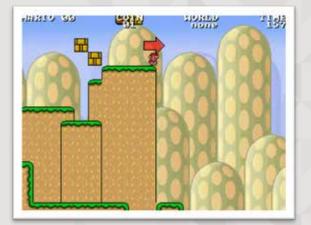
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- Design tools (19 papers)
- Design patterns (7 papers)
- Player modeling (5 papers)
- Real-time change during gameplay (7 papers)



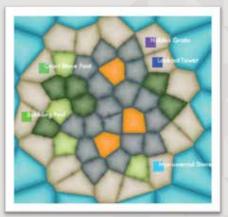
Towards Procedural Level Generation for Rehabilitation by D. Dimovska, P. Jarnfelt, S. Selvig and G. N. Yannakakis (2010) Teaching Japanese through Game Mechanics: An exploratory study by C. Olson, D. Kauffman, A. Fowler and F. Khosmood (2015) Scalable Level Generation for 2D Platforming Games by N. Dewsbury, A. Nunn, M. Syrett, J. Tatum and T. Thompson (2016)

- Design tools (19 papers)
- Design patterns (7 papers)
- Player modeling (5 papers)



- Real-time change during gameplay (7 papers)
- PCG as game mechanic (5 papers)





What is Procedural Content Generation? Mario on the borderline by J. Togelius, E. Kastbjerg, D. Schedl and G. N. Yannakakis (2011) Anza Island: Novel Gameplay Using ASP by K. Compton, A. Smith and M. Mateas (2012) Towards Procedural Generation As Gameplay: CLAY and Tombs of Tomeria by M. Cook and S. Colton (2016)

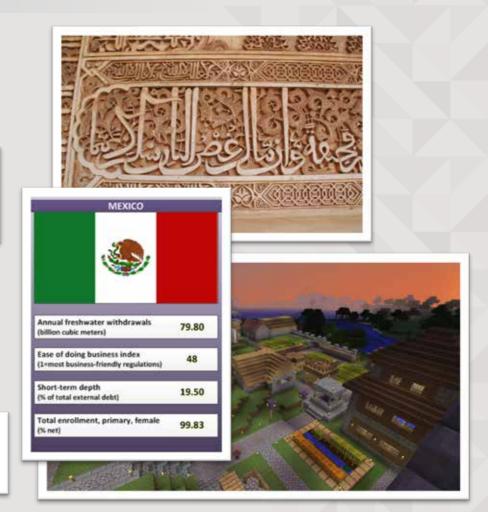
Vision papers (8 papers)

Art and Science of Engineered Design: What Kind of Discipline is PCG?

Little Procedural People

Playing politics with generators

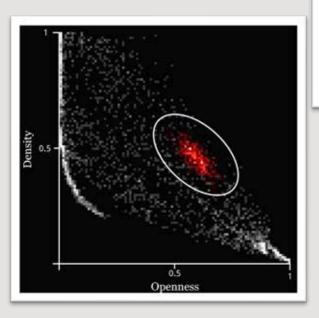
Characteristics of Generatable Games

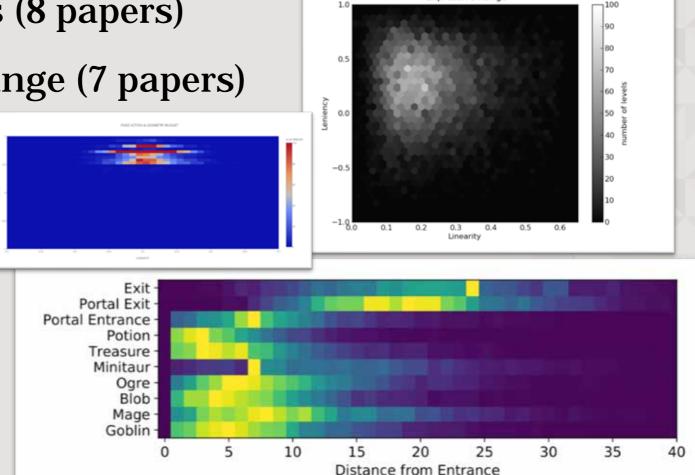


- Toward Procedural Decorative Ornamentation in Games by J. Whitehead (2010)
- Data Games by M. Gustafsson Friberger, J. Togelius, A. Borg Cardona, M. Ermacora, A. Mousten, M. Møller Jensen, V-A. Tanase and U. Brøndsted (2013)
- Characteristics of Generatable Games by J. Togelius, M.J. Nelson and A. Liapis (2014)
- Little Procedural People: Playing politics with generators by K. Compton (2017)
- Art and Science of Engineered Design: What Kind of Discipline is PCG? by J. Whitehead (2017)

Generative Design in Minecraft (GDMC): Settlement Generation Competition by C. Salge, M. Cerny Green, R. Canaan and J. Togelius (2018)

- Vision papers (8 papers)
- L Expressive range (7 papers)

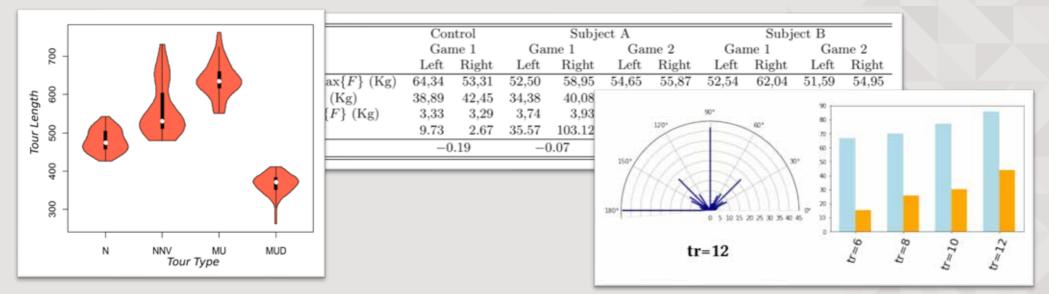




Expressive Range

Analyzing the Expressive Range of a Level Generator by G.n Smith and J. Whitehead (2010) Scalable Level Generation for 2D Platforming Games by N. Dewsbury, A. Nunn, M. Syrett, J. Tatum and T. Thompson (2016) Danesh: Helping Bridge The Gap Between Procedural Generators And Their Output by M. Cook, J. Gow and S. Colton (2016) Two-step Constructive Approaches for Dungeon Generation by M. Cerny Green, A. Khalifa, A. Alsoughayer, D. Surana, A. Liapis and J. Togelius (2019)

- Vision papers (8 papers)
- Expressive range (7 papers)
- Evaluation (32 papers), even if 92% papers technical



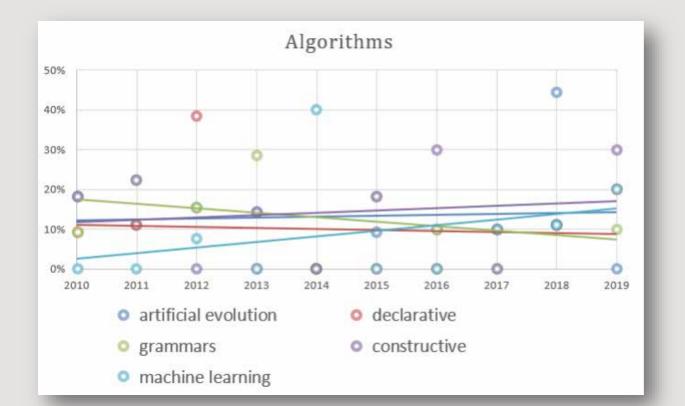
*Quantitative analysis of multiple runs of the generator (with or without human testers) which reports aggregated statistics and/or performs significance tests

Towards Procedural Level Generation for Rehabilitation by D. Dimovska, P. Jarnfelt, S. Selvig and G. N. Yannakakis (2010) Exhaustive Exploration Strategies for NPCs by M. Chowdhury and C. Verbrugge (2016) TownSim: Agent-based city evolution for naturalistic road network generation by A. Song and J. Whitehead (2019)

Parting Words

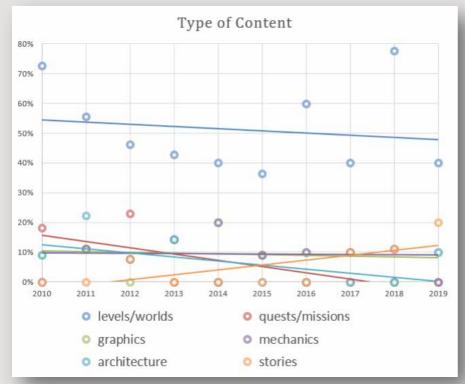
Takeaways

 Deep learning becoming commonplace and bringing new life to other methods



Takeaways

- Deep learning becoming commonplace and bringing new life to other methods
- Level generation will never go away, pushed by industry, competitions, libraries



Takeaways

- Deep learning becoming commonplace and bringing new life to other methods
- Level generation will never go away, pushed by industry, competitions, libraries
- Level gen and constructive methods easy
- We need an industry success and/or build communities & libraries for other content
- Minecraft is well-poised to be the next PCG favorite

Caveats

- This is a survey of the 95 PCG workshop papers
- Workshops focus on WIP and in discussion points
- Each year, local authors/groups submit

- Yet the PCG workshop encompasses much of the PCG community in Game AI...
- ...but we as a community have different interests than e.g. the CC community (e.g. DL for visuals)



