

# Computational Support for Play Testing Game Sketches

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## Abstract

Early-stage game prototypes need to be informative without requiring excessive commitments. Paper prototypes are frequently used as a way of trying out core mechanics while leaving them easy to change. Play testing on even these early-stage prototypes can give an idea of how the rules play out and whether the game is fun and engaging. Recently, researchers have proposed using automated analysis of games to discover additional properties of games, such as exploits and other gameplay issues.

We propose a lightweight game-sketching approach to give designers access to insight derived from both human and machine play testing. Using our system, BIPED, a designer specifies a game’s mechanics and maps them to a set of board-game-like primitives. Games created with BIPED can be played interactively on a computer as well as automatically analyzed, giving designers two complementary sources of design backtalk.

In this paper, we describe the language designers may use to sketch games, how they might use our tool in the two modes of play testing, and how the prototypes are computationally realized. Additionally, we study using our system to prototype a game and examine it in human and machine play tests.

## Introduction

Prototypes, both physical and computational, are an essential tool in a game designer’s arsenal. In a popular game-design text, Fullerton (2008) defines a prototype to be “a working model of your idea that allows you to test its feasibility and make improvements to it”. At the earliest stages, the designer can operate purely conceptually, thinking up new mechanics and imagining how they might interact with each other and the player; but at some point all designers need to try them out. This has been described as getting *backtalk* from a design situation: the designer begins with some idea of how her design should work, but by trying out a prototype, she uncovers unforeseen new information on how it actually does work (Schön 1983). In game prototyping, that new information can be both in terms of player experience, observing player’s excitement or hesitation to take a critical action; and in terms of how the game’s rule system operates, laying bare gameplay exploits and additional solutions to counterintuitive puzzles.

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Physical prototypes are an early-stage game design and play testing tool, in which low-fidelity versions of a game’s core mechanics are mocked up. Even a complex real-time videogame can be prototyped using cards, tokens, dice, and similar physical objects (Sigman 2005; Fullerton 2008, ch. 7). These prototypes aim to let the designer get backtalk after minimal effort, before committing to the cost of building a computational prototype (though it may provide higher-fidelity backtalk). An important aspect of low-commitment techniques is the ease of exploring related ideas.

There is some gray area between physical prototypes and computational prototypes as well. One common way of using a computer to run the game’s rules while keeping things lightweight is to use a spreadsheet, either stand-alone or as a computational aid to physical prototypes. The designer writes the game rules in a scriptable spreadsheet, and has it update game state as players take actions (Fullerton 2008, pp. 216, 221, 246). This style of prototyping is best suited to numerically oriented games, such as physical or economic simulations. However, many of the elements used in physical prototypes do not transfer well to spreadsheets. Instead, there are discrete cards and tokens, and rule systems with many cases and spatial rearrangement of the tokens, rather than equations that update numerical fields.

We propose a game-sketching approach to provide computational support for the class of physical prototypes that use board-game like elements to represent complex videogames. Through this approach, game designers can access formal analysis afforded by computational approaches while designing prototypes similar to those made with physical methods. The designer specifies game state, possible player actions, and state update rules. Elements of game state can be mapped on to a simple set of board-game primitives—connected spaces and tokens—and user actions are mediated by UI affordances such as clicking and dragging, constituting a fully playable game suitable for early play testing. Using logical reasoning, we also allow the designer to query formal properties of their sketch, such as getting examples of possible gameplay traces resulting in specific outcomes (or using specific means to achieve these). Our contribution is a technique that supports machine and human play testing, using a single game-sketch definition, to provide designers with the best of two complementary sources of backtalk.

## Play testing background

What can designers get out of play testing, and why would they need both kinds? We review discussions of human play testing in the game design literature, and proposals for machine play testing in the artificial intelligence literature, to provide a background for the kinds of design backtalk that have been proposed as particular strengths of each approach, especially as applied to early game prototyping.

### Play testing with humans

Fullerton (2008, ch. 7) has an extensive discussion of early prototyping and the kinds of design questions play testing with them can answer. She describes four main stages of prototyping. In the first, the designer focuses on foundations, looking at only a loose version of the core mechanics and avoiding filling in details like how many squares a player can move; the designer self-tests to validate and flesh out the design. In the second, the focus is on the game's structure, specifying rigid mechanics such as combat-resolution rules. The third stage fills in formal details and tweakable constants, such as starting health level and hit percentages, as well as minor elaborations on mechanics. In the last stage, the designer focuses on game flow and understanding how features of the game contribute to the play experience.

Implicit in most discussions of play testing is that important elements of gameplay come from intrinsically subjective human reactions. Koster (2004) focuses in particular on fun and engagement and their relation to an individual's process of learning a game's mechanics. Eladhari and Mateas (2008) discuss feedback from paper prototypes testing a game mechanic derived from personality theory, with play tests focusing on how the mechanics connect to players' personalities and subjective gameplay experiences.

### Play testing with machines

Although the subjective human experience of games is the key to their success, designing games involves crafting formal rule systems and understanding how they operate as well. Salen and Zimmerman (2004, ch. 12) discuss emergent properties of game rules, since a small set of rules might actually imply a larger set that are not explicitly specified; understanding these implications can help a designer decide how to revise the game towards its intended subjective experience. Since the formal properties of game rules are amenable to automated reasoning, Nelson and Mateas (2009) study what kinds of objective questions designers would find useful to ask; automatically providing answers to those questions would free up the designers to focus on more subjective design issues.

Salge et al. (2008) apply artificial intelligence to play testing, going as far as to argue that automatic testing can be superior to human testing, because human testers instinctively try to play in a balanced and fair style. An automated agent, by contrast, could look for exploits in the game rules without preconceived notions of how the game should be played.

Nelson and Mateas (2008) propose that designers prototype their early rule systems in a formal language, in exchange for which they can receive abstract gameplay traces.

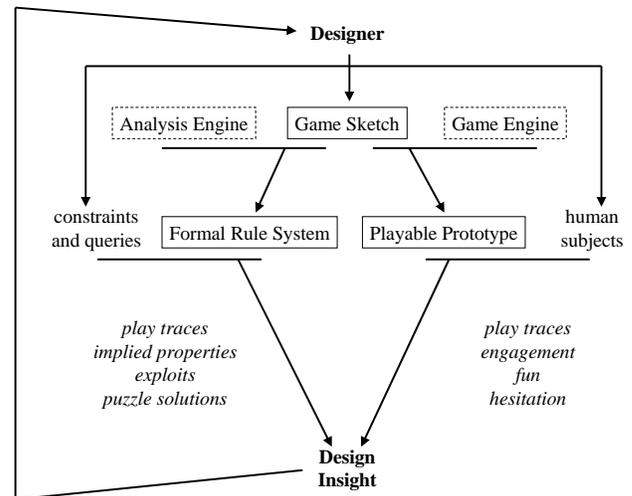


Figure 1: Architecture diagram for the BIPED system.

These play traces may illustrate interesting or undesirable gameplay possibilities that motivate a change, finding early issues with the game rules before spending time on human play testing (or even writing code for input and graphics).

### System overview

The architecture of BIPED, with its dual support for human and machine play testing, is shown in Figure 1. A designer using our system begins by writing a game sketch. This sketch is combined with an analysis engine to produce a formal rule system on which the designer can perform machine play testing. To do so, she specifies combinations of queries and constraints and can get back abstract gameplay traces with specific characteristics, determine implied properties of the rule system, find exploits, and list solutions to puzzles. The sketch can also be combined with our game engine to produce a playable prototype, which, when the designer or human subjects she recruits play it, can give feedback on more subjective properties of the game, such as player engagement, fun, or hesitation, as well as traces of actual gameplay. From these two sources of backtalk, design insight may prompt the designer to perform another iteration. We should emphasize that our approach focuses on early design prototypes, not late-stage prototype implementations of a full game.

### Game sketching language

Game sketches are defined in a subset of Prolog (chosen for its clean, declarative style); an example defining an inventory mechanic is shown in Figure 2. The designer can use logical predicates and constants to specify the entities in the game world and their properties. In this example, there are two agents, the player character and a thief; as well as two items, a bunch of loose coins and set of assorted gems. Entire levels can be described in a similar manner, specifying, for example, the rooms of a dungeon and hallways

```

agent(pc).
agent(thief).
item(loose_coins).
item(assorted_gems).

game_state(has(A,I)) :- agent(A), item(I).
game_event(drop(A,I)) :- agent(A), item(I).
terminates(drop(A,I),has(A,I)) :- agent(A), item(I).
possible(drop(A,I)) :-
    holds(has(A,I)), agent(A), item(I).

```

Figure 2: Snippet of the game sketch language defining part of an inventory mechanic. The last rule, for example, says: the game event that an agent drops an item is only possible if the agent has the item, for any agent or item.

between them.

A special set of predicates is recognized by the language. These can be used to specify the dynamic parts of the sketch, organized around *game state* and *game events*. The game state is a set of properties that vary over time, under the influence of game events. The game engine and analysis engine are implemented so as to provide a common semantics for these predicates, ensuring what is possible in the human-playable version is possible in the logical version and vice versa. Returning to the example in Figure 2, the *has* game state specifies, for any agent and item, whether the agent has that item. The next rule specifies a *drop* event (for any agent and item). The following rule gives the event’s effect: it terminates the *has* state (sets it to false). The final rule specifies that a *drop* event is only possible when the *has* state *holds* (is true). Similar, but not shown in this example, are *initiates*, which is analogous to *terminates* but specifies that an event sets an element of game state to true; and *conflicts*, which specifies restrictions on when events can happen simultaneously. The *initially* predicate can also be used to specify the elements of game state that hold at the beginning of the game.

**Interface elements**

To complete the prototype, a set of interactive visual elements are available to specify a game’s playable representation. Based on the kinds of representations often used in simple physical prototypes, the main interface elements are clickable tokens and spaces, with optional connecting lines between spaces. Figure 3 shows an example of the interface presented to the player. Figure 4 gives a simple example of setting up interface elements and connecting them to a game world. In this code example, there is a visual board space for every room in the game world (as well as a token for every item). Clicking on a board space that represents a room is set to trigger a *move\_to* event in the game world for that room (similarly for tokens and grabbing of items).

As with actual physical prototypes, there are many ways of using the visual elements to represent the state of the game world, and mappings need not all be as direct as in this example. Spaces can instead be used to represent inventory, with tokens on the space representing items in the inventory;

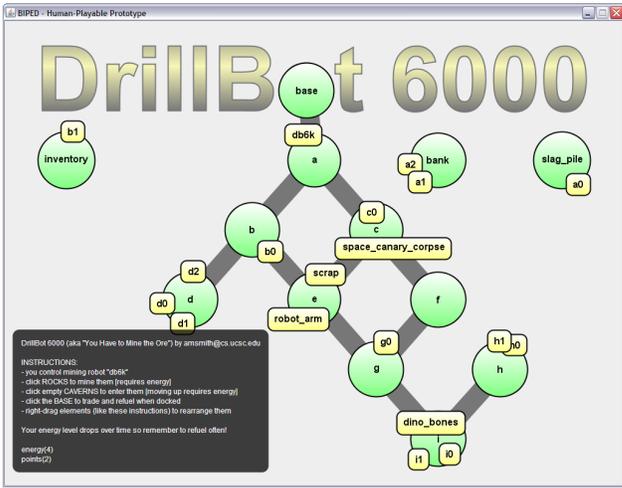


Figure 3: Human-playable prototype for our example game.

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ui_title('My adventure game').
ui_space(R) :- room(R).
ui_token(I) :- item(I).
ui_triggers(ui_click_space(R), move_to(R)) :- room(R).
ui_triggers(ui_click_token(I), grab(I)) :- item(I).

```

Figure 4: Bindings from UI elements to a game world.

or they can be buttons, with clicks causing a state change that may be reflected in a different part of the visual representation; or space and token combinations can represent turns or phases of the game (just as a physical dealer token is passed around a poker table). Similarly, connecting lines need not only represent how tokens can move between spaces; they might represent other relationships between entities represented by the spaces, or elements on which a button would operate when pressed. As a result of this flexibility, the designer does need to recall that there is no automatic meaning of the UI elements in terms of the game-world state: instead, it is their responsibility to give the representation elements game-relevant semantics.

In addition to the visible elements, our event system is a major representational tool. Time in the game world logically stands still until an event happens. The only sources of events are mouse interactions and expiration of timers. The effect of a living game world can be achieved using a ticker to create a regular stream of tick events, which can trigger interesting game-world events. The *ui\_triggers* predicate defines these mappings from mouse-interaction and timer events to game-world events; it checks to ensure that it only triggers game-world events if they are *possible* at the time.

We have been able to mock up a wide range of physical prototypes using this set of elements, and have avoided introducing a larger range of special-purpose elements in order to keep the prototypes simple and easy to modify. We have, however, included a number of aesthetic elements that do not directly represent game state, such as instructions, ti-

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happens(fires_at(jack, right), 0).

display_to(time(1), jill, health(2), enemies_at(right)).
display_to(time(1), jill, health(2), self_at(left)).
display_to(time(1), jack, health(1), enemies_at(left)).
display_to(time(1), jack, health(1), self_at(right)).

happens(fires_at(jill, right), 1).
happens( frags(jill, jack), 1).

display_to(time(2), jill, health(2), enemies_at(right)).
display_to(time(2), jill, health(2), self_at(left)).

```

Figure 5: Partial trace from a multiplayer shooter game prototype, illustrating events and game state over time.

tle, victory/loss animations, and background music, that can be used to provide an interpretive framework for the human play testers. We acknowledge that aesthetics of even early-stage prototypes can set the mood for the game and impact the subjective play experience, even if they are not the main focus (Sigman 2005). In particular, end conditions that support a subjective distinction between good and bad outcomes are a key feature of games (Juul 2003).

### Supporting play testing

To play-test games created using BIPED, the designer may begin with either machine or human testing; we have found that each process informs the other, so alternating between them may be useful.

Human play testing often begins with self-testing. The designer loads a game definition that she has created into the game engine, and is presented with an initial playable game. Even before mechanics are fully specified, it is often gratifying to see on-screen a level previously only described in the abstract. As the mechanics of a paper prototype are added to the first computational prototype, many design decisions have to be made to create the desired rigid rule system. A lightweight cycle of revision followed by self-testing can allow the designer to quickly flesh out these rules while playing the game themselves, giving a first glimpse at the gameplay possibilities afforded by their sketch.

When testing with others, it is important to formalize any parts of the game that the designer may have been keeping in their head during self-testing. By utilizing timers, on-screen instructions, and background music, the designer can externalize the desired dynamics and mood of the game (*e.g.* fast-paced and frenzied). Human play testing is best mediated by the designer, who can then observe player engagement and hesitation, as well as make verbal clarifications. Because playable prototypes from BIPED are user-tweakable, standalone sketches, however, they can be sent to and played by remote individuals as well (unlike physical prototypes or computational prototypes with extensive dependencies).

Play testing with humans is a well established practice; in contrast, play testing with machines is a relatively new, speculative idea. Thus, we have opted to focus on support for extracting gameplay traces, because these seem to be strongly

tied to player experience (as opposed to generating game-playing agents).

A designer can specify scenarios and conditions, and the analysis engine will provide her with gameplay traces (if any exist) starting from those scenarios and meeting those conditions. Figure 5 shows a short excerpt of a trace from a multiplayer shooter prototype, in which an agent, interestingly, inflicts damage on himself. To look for an exploit, the designer might ask for traces starting in a particularly tricky scenario, which end in victory only a few timesteps later. If any traces exist, the designer has a specific example of the behavior to forbid in the game rules; if not, the engine has proved that no such exploit is possible (which would be difficult to determine with certainty using only human play testing). In cases where there are many uninteresting traces, the designer can restrict the conditions in order to “zoom in” on more plausible gameplay. Alternatively, the designer can run experiments in which the scenario and conditions are held constant, and some element of the rules is changed. This gives the designer backtalk regarding a possible rule change rather than more detailed inspection of a particular rule set.

### Implementation

Our implementation is primarily split between two engines. The game engine, supporting human-playable prototypes, was implemented in the Scala programming language, which targets the Java Virtual Machine for easy redistribution of games. The rules of a particular game, implemented in Prolog, are interpreted using jTrolog,<sup>1</sup> a Prolog engine for Java, so game sketches can be modified by end users without recompilation. The game engine executes the game rules by advancing time in response to UI events, querying Prolog to find whether visual elements have changed (*e.g.* whether tokens have moved), and which elements of game state hold on the next time step.

The analysis engine, supporting the construction of complete formal rule systems, was implemented in Lparse/Smodels,<sup>2</sup> an answer-set-programming toolchain. Building on the work of Nelson and Mateas (2008), we used a representation of game worlds in the event calculus, a logical formalism for reasoning about time, and designed the declaration of game state and game events so they map directly onto event-calculus fluents and events. A compiler written in Prolog translates the game-sketch definitions into answer-set programs usable by Lparse. Additionally, a small Lparse “game engine” ties the rest of the game sketch (excluding UI) into the event-calculus semantics. The analysis engine is also responsible for checking that a game sketch is complete (defining a minimal set of required predicates) and checking any additional designer-specified static properties (*e.g.* there are no rooms in the level description without an adjoining hallway).

An interesting result of this translation is that when the analysis engine is looking for traces, it treats time as a symbolic constraint rather than simulating game worlds forward

<sup>1</sup><https://jtrolog.dev.java.net/>

<sup>2</sup><http://www.tcs.hut.fi/Software/smodels/>

in time. In this way, it is as easy to put constraints on initial conditions as it is on end conditions, or on any point in between. In the game engine behind human-playable prototypes, logical time, while discrete, behaves much more intuitively, advancing step by step in response to timers and human interaction (effectively finding a single trace).

### Example prototype

To exercise play testing with BIPED, we created *DrillBot 6000* (previously illustrated in Figure 3). In this game, the player moves a mining robot through underground caverns, drilling out rocks of mixed value, while managing energy usage by periodically returning to the surface to refuel and trade items. This game was designed as if to be an early prototype version of the popular Flash game *Motherload* from XGen Studios.<sup>3</sup> Our game focused on the core mechanics: moving around underground, mining, and refueling (whereas *Motherload* includes shopping for upgrades and story elements).

### Game mechanics

To describe the mechanics of the *DrillBot 6000* game world, our sketch definition asserts that *position* and *energy* are elements of game state (that apply to the one robot), and that subterranean rocks can be *present* in a cavern, *bagged* in the robot's inventory, or possibly *banked* after trading. In terms of game events, we allow mining of rocks, moving up or down between caverns, refueling, trading rocks, and spontaneous energy drain. The game sketch also defines the consequences of these events, and when they are possible. For example, the *mine* event for a rock *initiates* the *bagged* state for that rock, *terminates* its *present* state, and drains a unit of *energy*. This *mine* event is *possible* if: the rock is *present*, the location of the rock is reachable from the robot's current *position*, and the robot has *energy*. The rigid rules for other game events are defined similarly. Finally, the definition asserts initial conditions: the robot starts fully energized at the base, and all rocks are present.

### UI bindings

While the game mechanics described above are enough to allow machine play testing, for human testing we needed to expose the abstract game world to the player. Caverns are mapped to board spaces, and the up/down links between caverns are visualized with connecting lines. Individual tokens represent the minable rocks, and a special token represents the robot itself. The UI event of clicking a rock's token is bound to the *mine* event for the corresponding rock. Likewise, clicking a cavern's space is bound to either a *move\_up* or *move\_down* event to that cavern. These bindings are expressed concisely without need to reiterate the necessary conditions (e.g. the proper *move\_up* or *move\_down* event is selected by virtue of the game-world definition of when these events are *possible*).

We bound the position of rock tokens to cavern spaces using the abstract level definition and the *present* status of

the rock to select a space. When rocks are not present, the player should have a way of knowing the rock's *bagged* or *banked* status. The additional spaces called *inventory*, *bank*, and *slag\_pile* are used as the location for rock tokens that are no longer present but have differing bagged or banked states (valueless rocks cannot be banked, and their tokens are sent flying to the slag pile with a quick animation). Spaces themselves are anchored to the board with an optional predicate; these positions were consciously set to portray the directionality of links between caverns.

To give our prototype an element of the time pressure present in *Motherload*, there is a ticker for which the tick event is bound to the game world's *drain* event, draining a unit of the robot's energy. Thus, robot energy drains at a regular pace, but faster when the player actively triggers game-world events that consume energy. Energy is replenished by clicking on the base's space, which triggers the game-world *refuel* and *trade* events simultaneously.

A game definition also specifies several non-interactive elements. A large title and background music set the tone for a lively real-time mining game. On-screen, written instructions lay out both the premise of the game and explain how the player can use the mouse to take actions in the world of rocks, caverns, and a robot. Some elements of game state not mapped to spaces and tokens are depicted textually, in this case energy level and score. Finally, when the game determines that no additional actions are possible, a few tokens fly onto the screen to announce the game's outcome.

### Human play testing

As suggested by Fullerton (2008, p. 252), since we were testing the foundations and structure of the game, we primarily tested *DrillBot 6000* by self-testing and testing with confidants. Self-testing revealed that our early iterations had allowed unintended gameplay; for example, you could mine a rock at arbitrary distances. Additionally, we found the first version of the game too simple, and decided to add several additional rocks and caverns. When testing with others, one tester initially felt pressured by the speed of the automatic energy drain. While we could have adjusted the speed of energy drain or the maximum energy level, at this stage of the prototype we were interested in more foundational questions, rather than game balancing. To get feedback on the game's other mechanics, we showed the tester how to convert the game to a turn-based one by removing the ticker. All three testers claimed to enjoy the game, and could reach rocks at the deeper levels after some practice. Interestingly, no testers related to the game as a puzzle or path-planning challenge, even in turn-based mode; all focused instead on the action aspect of the game motivated by the continuously draining energy.

### Machine play testing

While human play testing validated that the game's basic concept was interesting, BIPED allowed us to turn to machine play testing to ask more detailed questions that would have been tedious or impossible to test with human testers. Because players focused on improving their speed, in machine play testing we decided to look at the limit case, corre-

<sup>3</sup><http://www.xgenstudios.com/play/motherload>

sponding to a player that could execute several actions without incurring any time-based energy drain (which was possible but difficult with our timer settings). This would allow us to focus on the energy cost of mining and moving as the limiting factors, effectively discovering speed runs.

In one experiment, we looked for gameplay traces that maximized the number of treasures the robot could bank by the end of a fixed number of timepoints. In 15 timepoints, we found that the ideal player could bank up to five valuable rocks. Then we asked about a player who would never refuel, wondering if this would place some rocks out of reach. Over this game length we found that the ideal player could still bank five valuable rocks, indicating that refueling is needed relatively infrequently. This was interesting, because our human testers refuelled quite often, as a hedge against energy drain, indicating that they were much more cautious with managing energy than strictly necessary.

In the setup for this experiment, when looking at general gameplay traces, we found undesirable traces in which several rocks were mined simultaneously. This revealed that we had not completely specified when game actions should conflict. That issue was not revealed in human testing, because the UI bindings happened to make it impossible to mine several rocks at the same time (which would not be the case if mining had been tied to clicks on spaces instead of on tokens). Finding that this design choice was incompletely specified both forced us to think about what mechanics we actually did want, and avoided the persistence of a UI-masked bug that could reappear in later prototypes.

In another experiment, we looked at a few properties of the level's design. One question involved asking how many caverns a player could explore in a given interval (where the robot starts and ends in the base). This query is particularly tedious to answer through human play testing, since it would require trying a vast number of possibilities. It also goes beyond simple graph search, because it takes into account the effects of time-varying presence of rocks due to mining. In 15 timepoints, a player can explore up to eight caverns before returning to the base. Making what we thought would be a radical change to the level's design, we added a direct link from the base down to the deepest cavern in the level. Running queries for reachable caverns and banked rocks again, we were surprised to find this change made no difference in the properties of the optimal play-through.

## Conclusions and future work

We have proposed a computational prototyping approach to combined support for human and machine play testing of early-stage game sketches. This approach has been cached out in BIPED, a tool that uses declarative game descriptions to produce both standalone, playable games and formal rule systems that admit automatically finding gameplay traces with specific properties (while minimizing design commitments, yet allowing sufficient interpretive affordances to support useful human play testing). We explored the process of designing with BIPED by prototyping *Drill-Bot 6000*, an action-oriented game in the style of *Motherload*. In doing so, we illustrated the synergy of human and machine play testing for insight into the game's design.

The semantics of our game-sketching language are based on a knowledge representation which is optimized for designer exploration, while the syntax used here was chosen in large part to minimize the distance to the two declarative reasoning engines involved. In future work, we intend to address the language's accessibility, particularly to game designers without a logic-programming background; it is best to think of the language presented in this paper as an intermediate representation. In addition, future work should investigate other reasoning backends for the analysis engine with better scaling and numeric processing capabilities.

Several miscellaneous improvements to this approach could be unified in a game-design "workbench" that bundles all the tools necessary for a designer to carry out exploratory game design, including a better query language paired with more intuitive visualization of results. Additionally, such a tool should provide a more fluid way of modifying a game's mechanics than editing a logic program.

A tool like BIPED is an interesting target platform for automated game generation research (whether aiming to create whole new mechanics or just tweaking level designs). Moving beyond generation, the addition of detailed instrumentation to the human-playable prototypes would admit collecting enough information from human play testers to inform the analysis used in an intelligent game-design agent that might learn from how humans play the games it produces.

Finally, an open problem is how to extend the human-machine play testing approach to later stages of the game-design process. For now, our approach is focused on allowing designer-programmers to take large creative leaps by getting rich feedback from simple, early-stage prototypes.

## References

- Eladhari, M. P., and Mateas, M. 2008. Semi-autonomous avatars in World of Minds: A case study of AI-based game design. In *Proc. 2008 Intl. Conf. on Advances in Computer Entertainment (ACE)*, 201–208.
- Fullerton, T. 2008. *Game Design Workshop*. Morgan Kaufmann, 2nd edition.
- Juul, J. 2003. The game, the player, the world: Looking for a heart of gameness. In *Proc. 2003 Digital Games Research Association Conference (DiGRA)*, 30–45.
- Koster, R. 2004. *A Theory of Fun for Game Design*. Paraglyph.
- Nelson, M. J., and Mateas, M. 2008. Recombinable game mechanics for automated design support. In *Proc. 4th Artificial Intelligence and Interactive Digital Entertainment Conference (AI-IDE)*, 84–89.
- Nelson, M. J., and Mateas, M. 2009. A requirements analysis for videogame design support tools. In *Proc. 4th Intl. Conf. on the Foundations of Digital Games (FDG)*.
- Salen, K., and Zimmerman, E. 2004. *Rules of Play*. MIT Press.
- Salge, C.; Lipski, C.; Mahlmann, T.; and Mathiak, B. 2008. Using genetically optimized artificial intelligence to improve game-playing fun for strategic games. In *Proc. Sandbox 2008 ACM SIGGRAPH Videogame Symposium*, 7–14.
- Schön, D. A. 1983. *The Reflective Practitioner*. Basic Books.
- Sigman, T. 2005. The siren song of the paper cutter: Tips and tricks from the trenches of paper prototyping. *Gamasutra*. <http://www.gamasutra.com/view/feature/2403/>.