Lessons Learned in Game Development for Crowdsourced Software Formal Verification

Presented by Drew Dean

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http://www.verigames.com

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Overview

- Problem Overview
- Case Studies
  - CircuitBot/Dynamakr
  - Flow Jam/Paradox
  - Ghost Map/Ghost Map: Hyperspace
  - Stormbound/Monster Proof
  - Xylem/Binary Fission
- Conclusions and Lessons Learned

Problem Overview

- Typical software has 1-5 bugs per thousand lines of code
- Formal verification can reduce this to 0.1 – 0.5 bugs per thousand lines of code
- However, formal verification is too expensive and time consuming
  - Typically 2x – 100x cost increase
  - Optimists will point to the times costs have decreased

Making Formal Verification Affordable

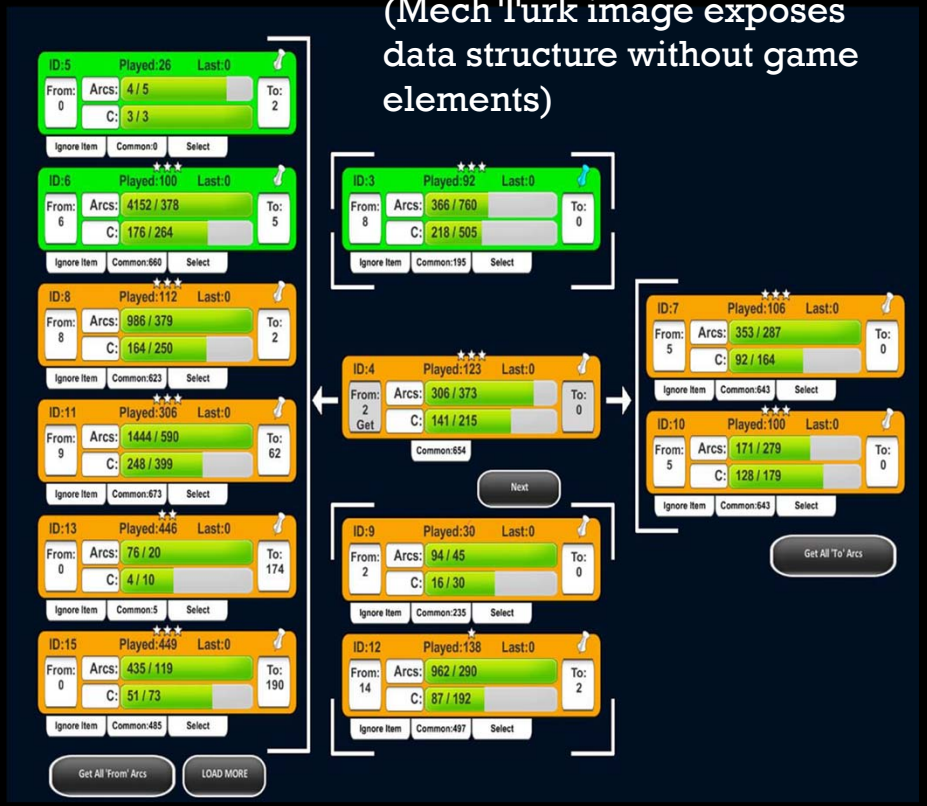
- How do we typically decrease costs?
  - Automation
- Alas, Rice's Theorem limits automation
  - All non-trivial properties of programs are undecidable in general
  - Much empirical support in practice
  - See Kathleen Fisher's talk on Thursday for progress in automation

Making Formal Verification Affordable

- Can we replace the expensive, highly trained computer scientists with the crowd?
  - Only if we make the tools far more approachable
  - Convert logic puzzles into games
  - Market …

Case Study: CircuitBot/Dynamaker Developing Points-to Graph

- Some types of automated verification require a points-to graph (i.e., graph of which pointers may hold which addresses at runtime)
- Determining reasonable approx-imations of the points-to graphs requires a high degree of graph intelligence (human or, perhaps, machine).
- Our auto-solver can run without human intervention. It is a research question whether it will compete with human experts in performance.

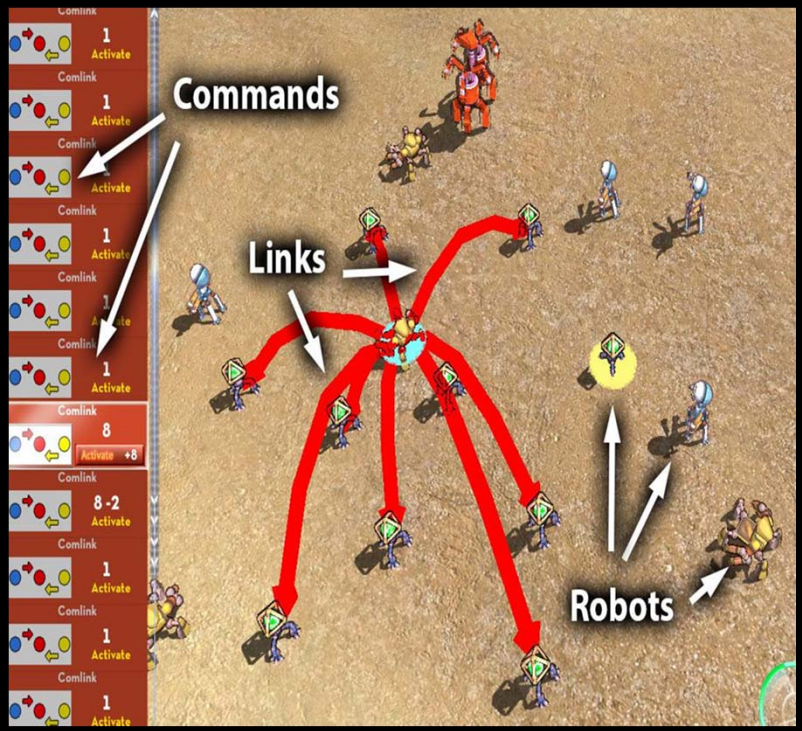


(Mech Turk image exposes data structure without game elements)

Team Authors:
Andrew Keplinger & Greg Izzo, Left Brain Games
Matthew Barry, Kestrel Technology
J. Nelson Rushton, Texas Tech University

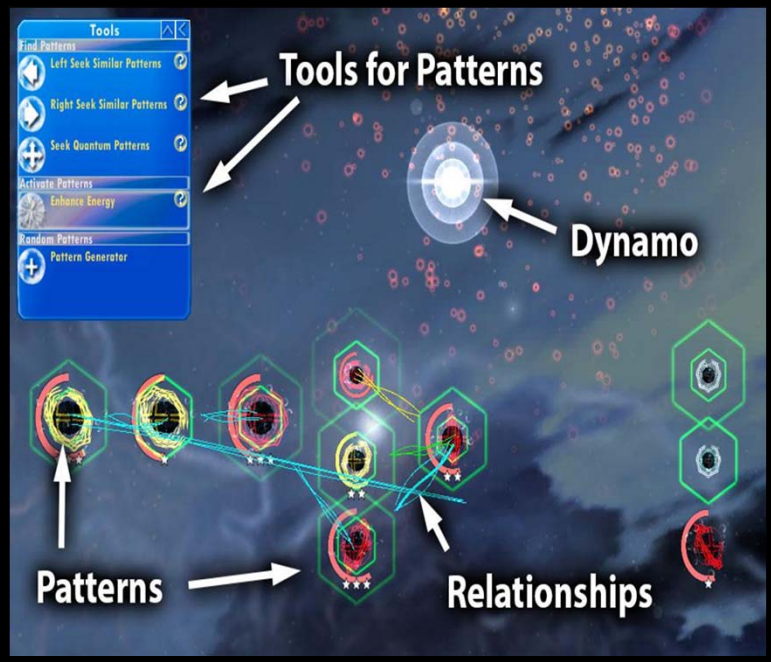
CircuitBot and Lessons Learned

- CircuitBot was developed to provide a framework for building the points-to graph
- Core game is designed to apply rules combined with existing information to produce relevant data
- Overarching exploration and strategy game provides motivation to replay core game
- Combination was effective at motivating certain types of players
- Rule development refinement could produce improved results
- Players could address much larger sets of rules if trivial content was filtered



Dynamakr

- Play multiple game instances simultaneously, illustrating how game results influence each other



- Find related games dynamically and determine play priorities for efficiency
- Auto-solver analyzers are embedded in the game, working alongside the player

Case Study: Flow Jam/Paradox Overview

- Input is a set of constraints over possible annotations
- Game level generated from constraints (links) and possible annotations (widgets) from code
- Widgets and links can be wide or narrow, links are the width of the widget they flow from
- Constraints include:
  - Jams on links
  - Bonuses on widgets
- Player assigns values to annotations to satisfy as many constraints as possible
- Output is desired annotation values

Team Authors:
Tim Pavlik, Craig Conner, Jonathan Burke, Matthew Burns, & Michael Ernst, University of Washington
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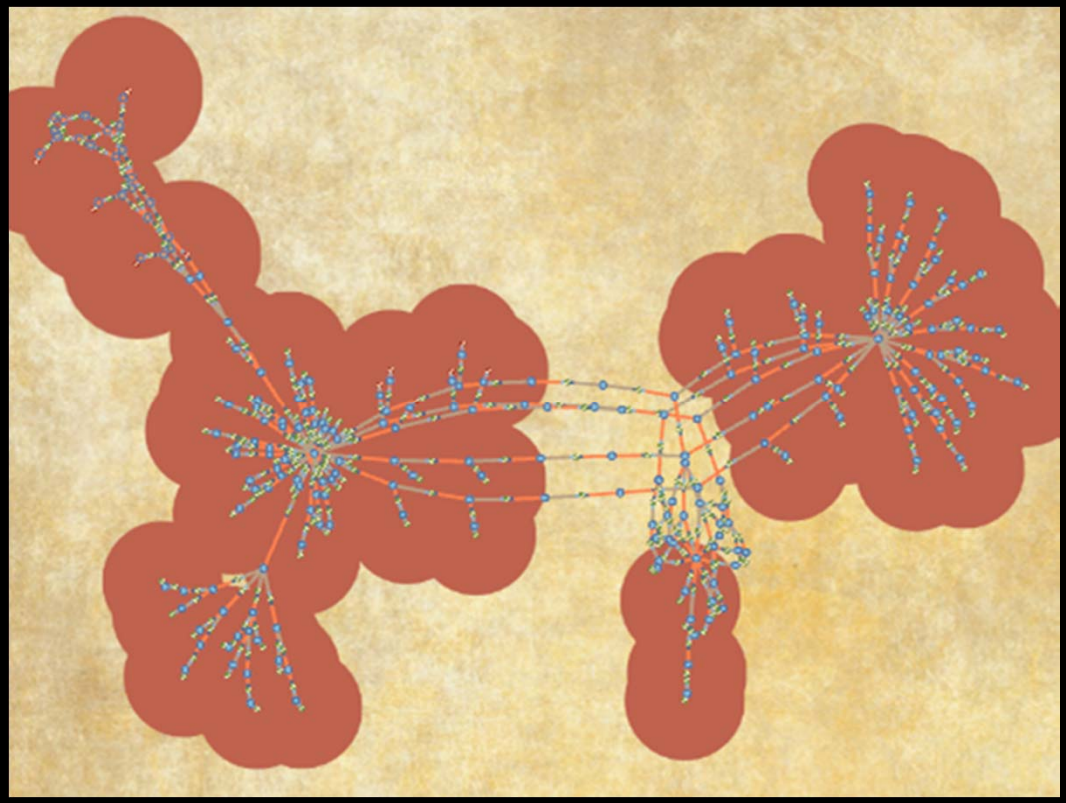
Seth Cooper, Northeastern University

Flow Jam: Lessons Learned

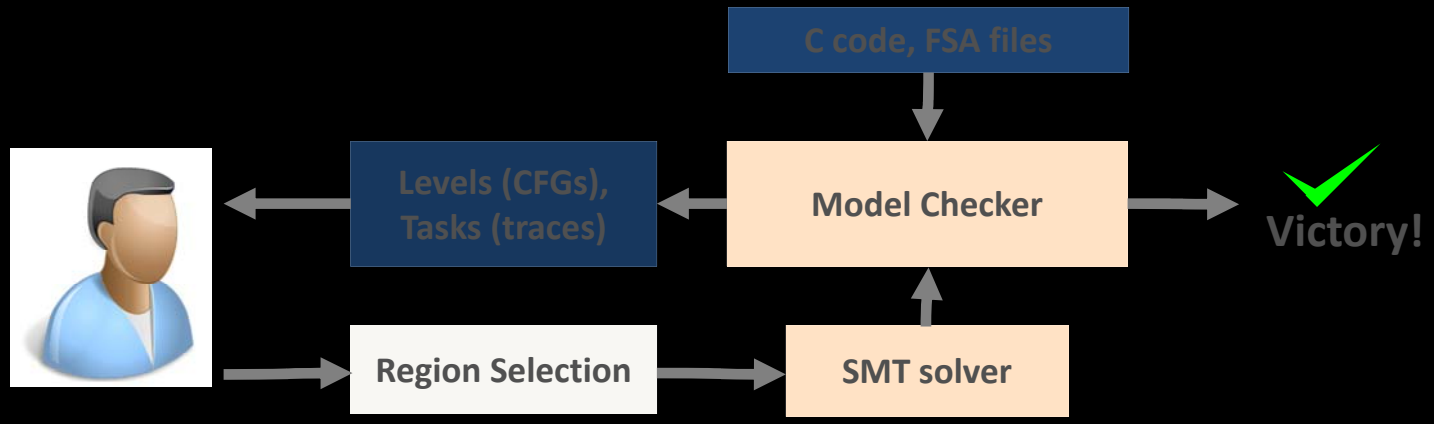
- For larger levels, toggling widgets individually was tedious
- Level layouts were difficult to understand
- Did not leverage human spatial reasoning

Paradox: Refined User Support

- Simplified graphical representation and improved graph layouts
- Allowed players to use auto-solve toolset for more rapid play
- Provided spatial painting mechanics to drive application of auto-solver



Case Study: Ghost Map



- Model checker finds counterexample traces
  - Violations of security property, encoded as FSA
- User selects region on trace to send to SMT
- Success means region unsatisfiable
  - Trace unrealizable; ergo false positive
- Modified graph sent back to model checker
  - Either done, or new trace

Team Authors:
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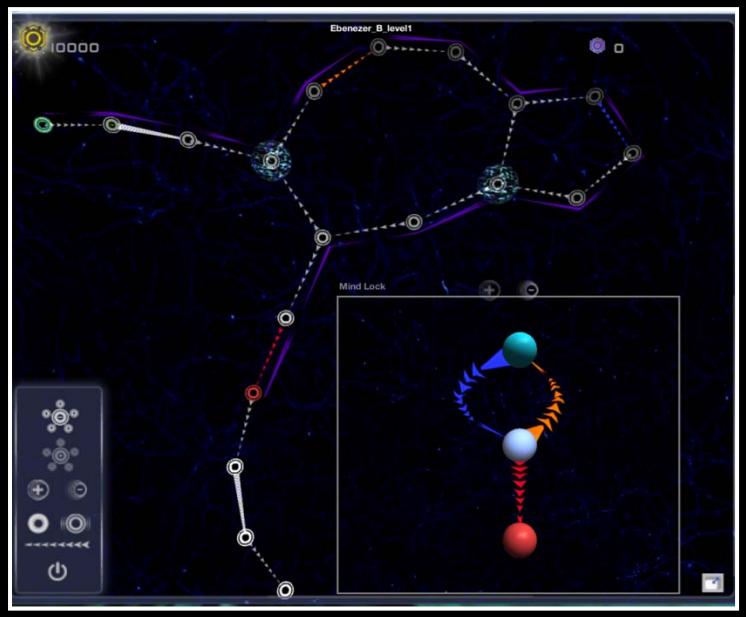
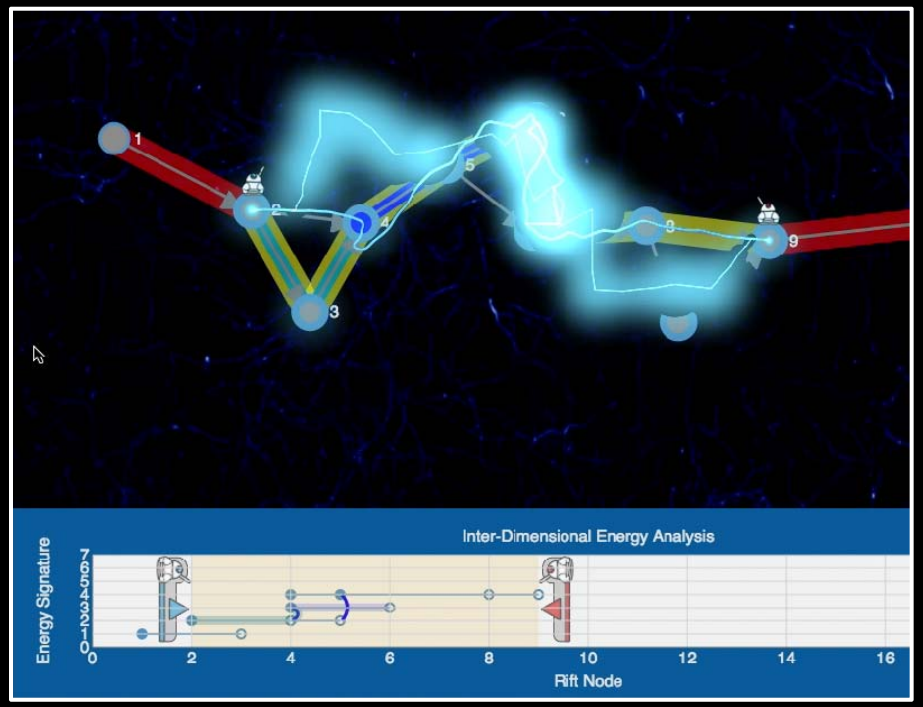
Eric Church, BreakAway Games

Proof by Games – Ghost Map



- Player
  - AI on verge of consciousness
- CFG
  - Map of player's own mind
- FSA
  - "Mind Lock" preventing consciousness
- Player Goal
  - Modify own mind to thwart "Lock"
- Challenges
  - "Mind Locks" difficult for players to understand
  - FSAs do not sufficiently guide player actions

Proof by Games – Ghost Map: Hyperspace



- New Approach
  - Do not show FSA
  - Instead show program variables
  - Add "pure entertainment" element to enhance engagement
- Player
  - Space mercenary
- CFG
  - Map of Hyperspace
- Program Variables
  - "Energy Signatures"
- Variable Dependencies
  - "Energy Chains"
- Player Goal
  - Seal "Hyperspace Rifts" to prevent alien invasion
- Challenges
  - Balance "pure entertainment" action game with the real math game
  - Program enough information about variable usage – but not too much

Case Study: StormBound and Monster Proof Verification Approach

- Verifying memory safety (e.g. no buffer overruns) of C programs
- Through gameplay, players create assertions about code at particular program points
- Game-generated assertions assembled into a proof
- StormBound: Players view multiple snapshots of program variables at single program point and look for common patterns, e.g. "i < sizeof(ary)"
- Monster Proof: Players build proofs directly using well-defined rules, trying to prove a precondition that must be true if a function is memory safe

Team Authors:
Aaron Cammarata, VoidAlpha
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Comparing StormBound and Monster Proof

StormBound	Monster Proof
	
• Story-driven engagement • Levels solved by *pattern matching* • "Magepunk" universe, blend of brass/steam and glowing magical runes • Goal of "hiding the math": allow players to make assertions without any math or numbers in-game • Targeted a broader, casual audience • Used Unity Webplayer, embedded in a MeteorJS web page	• Resource-gathering and collection • Levels solved by *reasoning* • Cute cartoon monsters, emphasis on tongue-in-cheek humor • Goal of "showing the math": give players tons of context, and focus on efficiency and comprehension • Targets a focused puzzle-game audience • Used Famo.us for HTML/CSS Sprites, and MeteorJS for web page / server

Lessons Learned

- Challenging to give players a sense of progress and completion
  - Solutions to levels are unknown *a priori*
  - StormBound: players supplied (and rewarded for) as many level solutions as they liked without clear completion point
  - Monster Proof: clear when a solution is correct, with optional opportunity to improve on it
- Players need sufficient context to ensure solutions useful for verification
  - StormBound: players could (and mostly did) inadvertently create true but useless assertions that relate variables with no semantic relationship
  - Monster Proof: reduced complexity of levels as much as possible, then gave players all needed context needed to reason about the level
- Exposing the underlying problem helps motivate players ("citizen scientist" message)
  - StormBound: we "hid the math," but players asked to see it
  - Monster Proof: messaging clear about how game play impacts verification

Case Study: Xylem/Binary Fission Overview

- Xylem presents problem as logical induction puzzle game
  - Players are botanists exploring a strange island
  - They observe and compare growth patterns of plants
  - Provide candidate invariants for the CSFV verification task in the process
- Binary Fission focuses on sorting colored atoms into two groups
  - Select from set of filters to perform sorting
  - Refine and merge invariant searches that have been performed by other games/automated systems

Team Authors:
John Murray, SRI International
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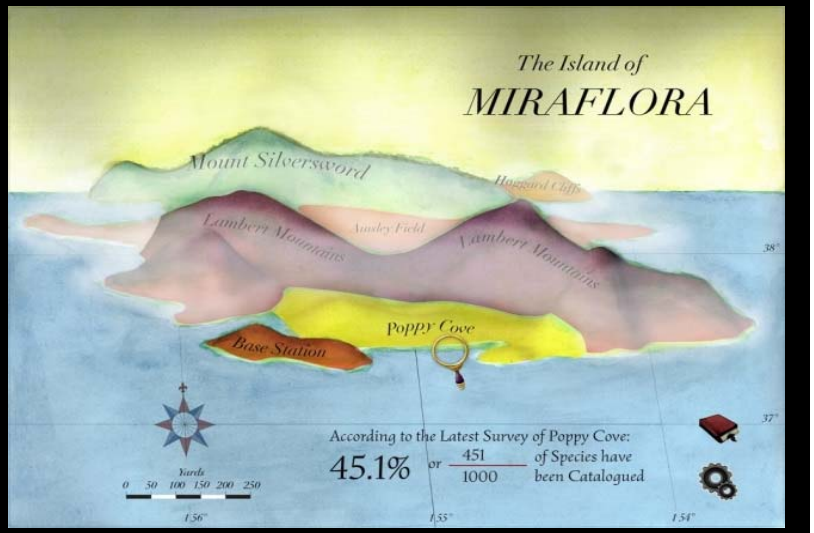
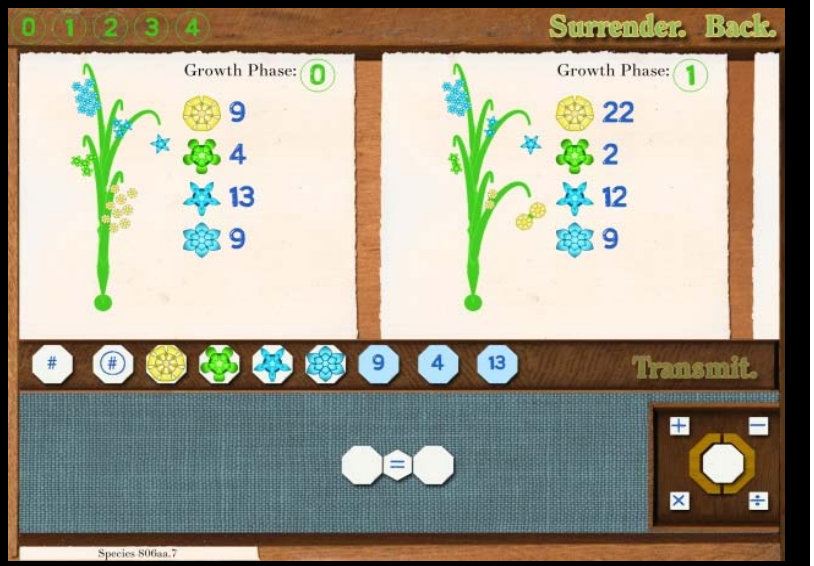
Xylem: Lessons Learned

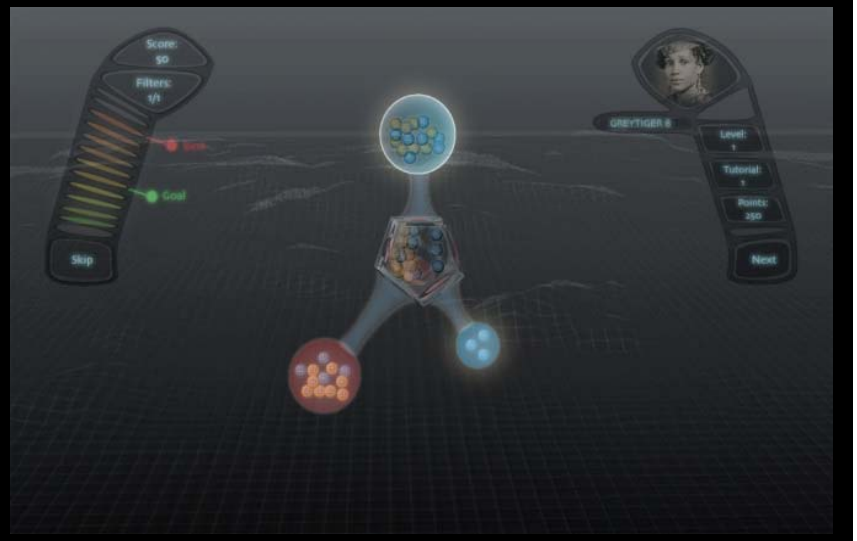
- Original goal focused on appealing to casual game audience by integrating puzzle-solving with evolving game narrative
- Casual gamers were not interested in mathematical gameplay
- Xylem complexity and lack of clarity led to limited players in casual gaming community



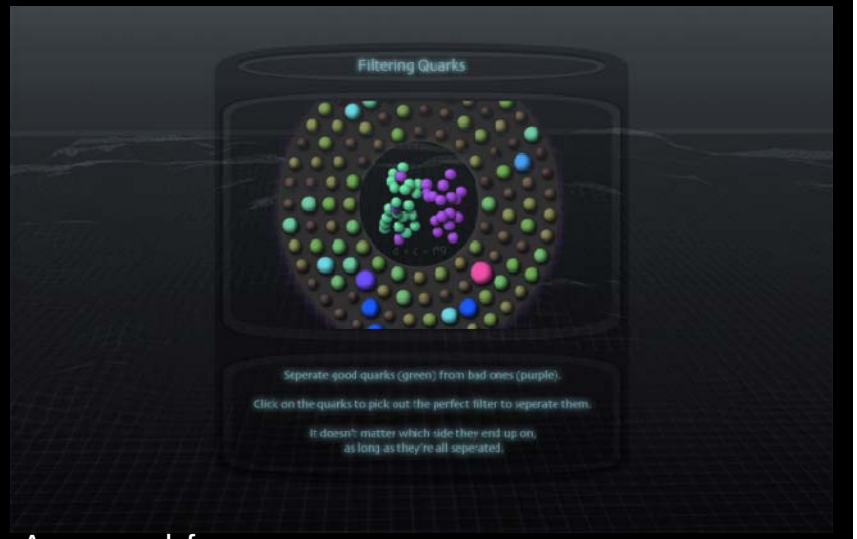


Binary Fission: Adapted to Support Citizen Science

- Binary Fission embraced citizen science approach by designing problems focused on a more mathematically inclined crowd



- Binary Fission also incorporated more cooperative game play, to foster community interaction in support of citizen science objectives



Conclusions/Lessons Learned

- *Know the player population*
  - Initial focus on engaging crowds with limited mathematical background – but these are not the high contributors
  - Problem better served by *citizen scientists* with mathematical expertise – later games were designed to this objective
- *Manage the complexity of the game design*
  - Use a progression of tools that teaches key concepts for contribution
  - Entertain players as new concepts are taught
- *Manage tradeoff between engagement and problem resolution*
  - Consider separating problem-solving process from fun and entertainment – incorporate engaging elements in downtime
  - Maximize the use of human intuition and insight
- *Use automation where possible*
  - Minimize busy work performed by the citizen scientists
  - Manage insertion of automation to ensure game players understand mechanics and impacts

Contact Points and Website

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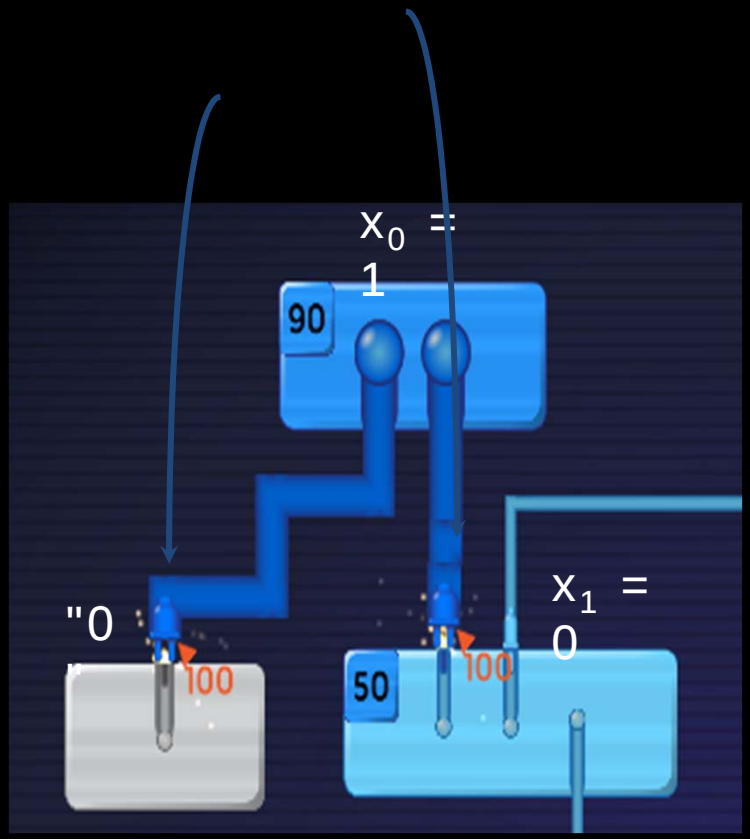
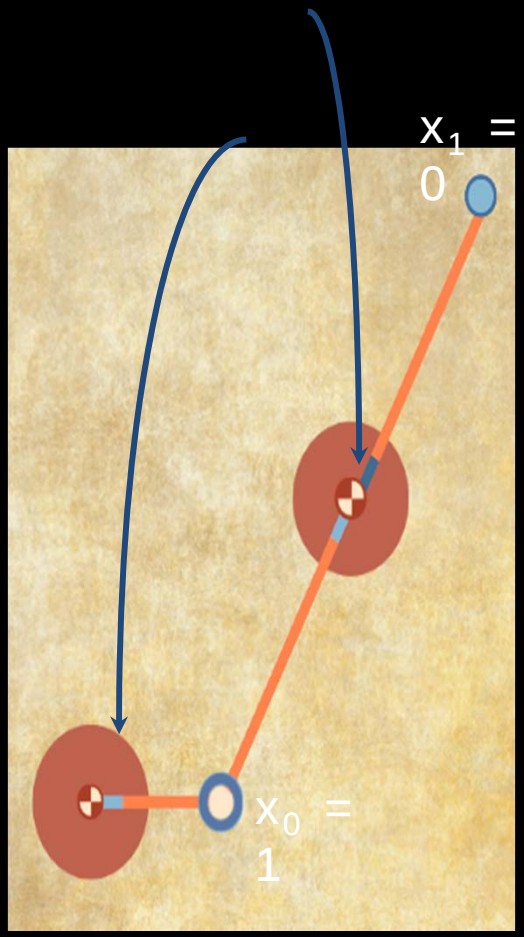
CSFV games can be found at http://www.verigames.com

Paradox Backup: Constraints

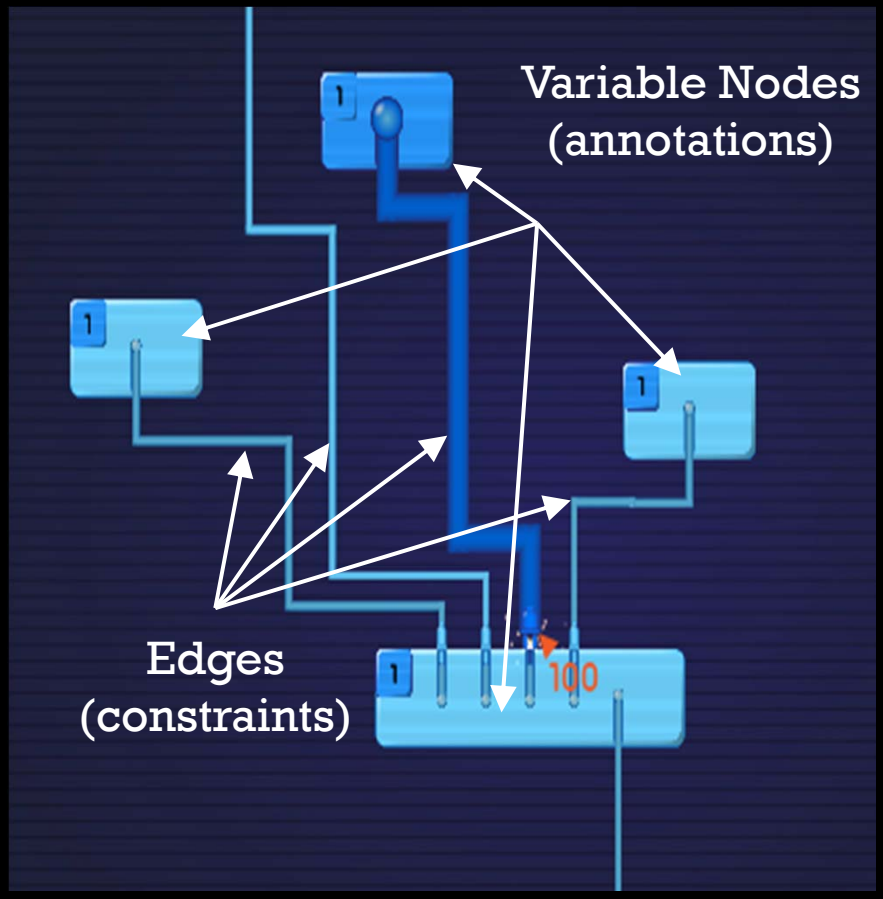


Flow Jam

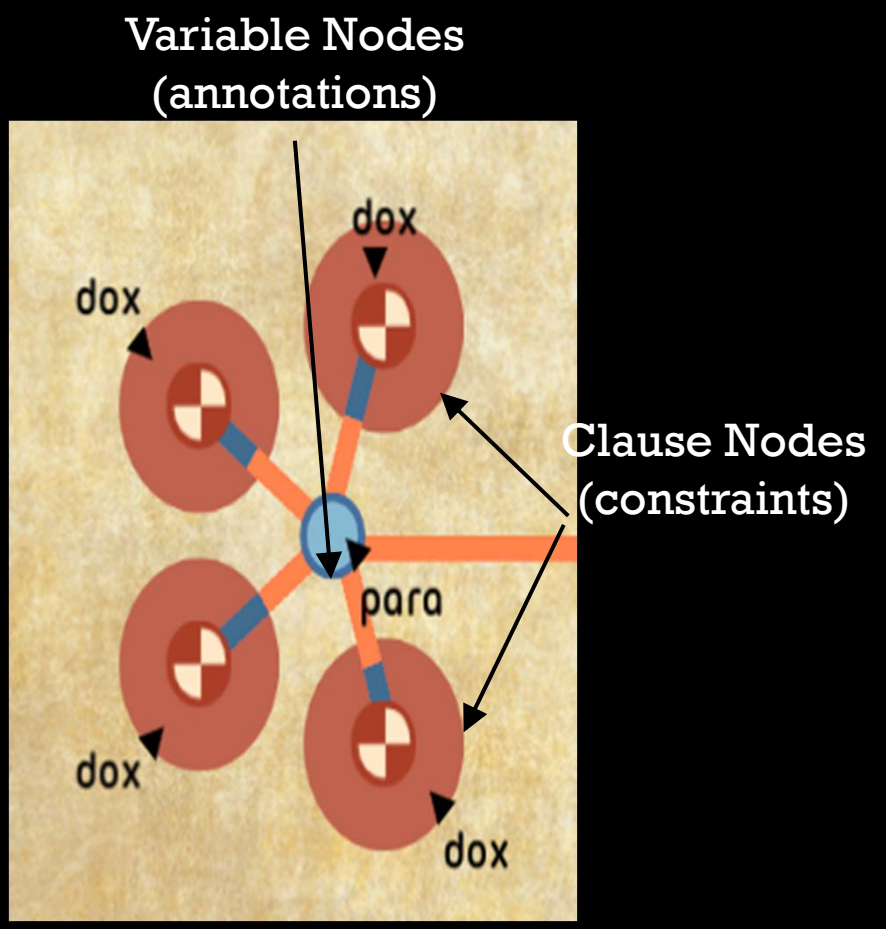


Paradox

Paradox Backup: Game Elements



Flow Jam



Paradox