

Xylem: The Code of Plants

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ABSTRACT

This paper describes the impetus behind and design of a quasi-casual math puzzle game with the goal of crowdsourcing formal software verification through the analysis of loop invariants. This game, Xylem: The Code of Plants, presents players with puzzles derived from data produced by loops in a particular piece of software. Solving these puzzles involves finding and expressing a loop invariant that holds for that set of data, which results in an annotation in the original code. In this way, players can contribute to the effort to formally verify a piece of software while enjoying mathematical puzzles.

Author Keywords

Game Design; formal software verification; serious games; loop invariants.

ACM Classification Keywords

L.5.1 Game Based Learning/Gaming; D.2.4 Software/Program Verification

INTRODUCTION

Formal software verification is a software engineering technique for modeling a software system's source code, and then proving properties about it such as freedom from security vulnerabilities. Though proofs are largely automated, formal source code modeling is time consuming and requires substantial human attention. Xylem: The Code

of Plants is an iPad game in which players make observations about unusual plants, and in so doing model the behavior of software loops. With large numbers of players, the goal of Xylem is to have players model the behavior of large software systems faster, and at lower cost, than is currently achievable by relying on formal verification experts alone.

The strategy used by Xylem for assisting formal verification of software is to have the players find and express loop invariants of loops from actual software code. Loop invariants are statements which must hold every time a loop is entered, either on the initial run or on subsequent iterations up to the loop's termination. If the loop invariant holds for the entire loop, then the loop can be thought of as having done the job intended by the programmer, and can therefore be considered provably correct.

As a crowdsourcing project, Xylem relies on achieving a critical number of players to submit loop invariants in order to make progress on software verification. Therefore, the game has been designed with a wide audience in mind and every effort has been made from the beginning of the project to create a compelling game experience. Rather than approaching the game from the perspective of solving a science problem by adding game-like elements to a close mapping of the science involved, Xylem: The Code of Plants is an interesting experiment in mapping a science problem to an alternate domain (in this case, botany) and in balancing game design and science concerns.

THE GAME

Taking on the role of a botanist in 1921, the player catalogs new plant species by describing patterns in the plants' morphology. While players solve puzzles and find patterns in fictional plants, they are simultaneously helping with real-world software security. As players solve puzzles, they are simultaneously providing loop invariants which in turn prove small pieces of the target software to be correct and free of possible common vulnerabilities. With many players

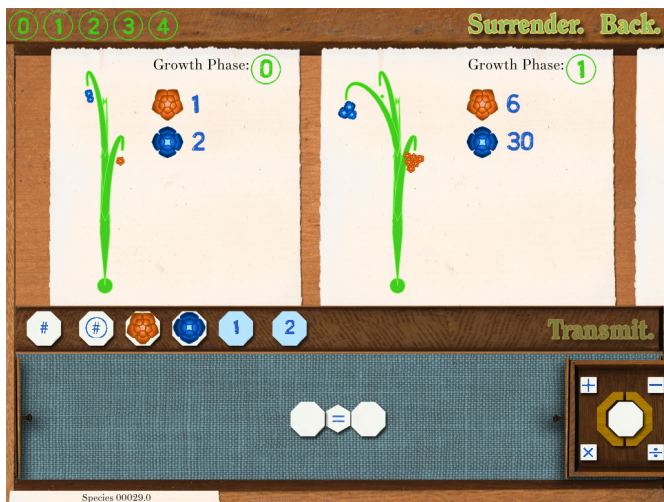


Figure 1. Puzzle Solving Interface of Xylem: Code of Plants

contributing, the cost of doing formal verification is reduced by shifting work from highly-paid experts. This frees up these formal verification experts to focus on the harder, more interesting, problems or to prioritize the efforts of game players.

In order to find a loop invariant, players must first examine the different growth phases of a given plant species by comparing samples (growth phases) of that species side by side. The player's job is to discover one mathematical rule that holds across every growth phase of that plant.

Once the player has intuited a solution that holds true for each growth phase, their task is to construct a mathematical equation that describes the pattern. The player is provided with a set of tool tiles that can be dragged into a central workspace and linked together to form these equations. If the created rule holds for a given growth phase, the background of the "slide" representing that growth phase turns green. The player has a successful solution when all slide backgrounds for a species turn green.

To attract as large a crowd of players for the game as possible, Xylem was originally designed with a wide audience in mind. Attention has been given to narrative and aesthetics which would appeal to a wide variety of people. Math skills required for success in the game have been limited to basic algebra whenever possible. Emphasis was originally on collaborative rather than competitive multi-player game play, with players working together to solve problems in one island region in order to unlock the next region for play.

ANALYSIS

While the main gameplay of Xylem has proven engaging to players, the game has attracted a different audience than it was originally designed for. Certain features, such as a discoverable narrative background, proved undesirable to the more mathematically and science minded players drawn

to the game. With this in mind, an update is in process that speaks less to the quasi-casual audience originally sought by the project and is instead designed to appeal to the more hardcore math puzzle audience that has found and enjoyed the game. This update will remove much of the background narrative and instead focus on providing a sense of personal progress and achievement, and includes a leveling system and unlockable upgrades.

Despite the fact that the game has not, as of yet, attracted the numbers that would make the crowdsourcing aspect unquestioningly successful, gameplay since launch has nonetheless provided results that contribute to code analysis of the target software which was previously impossible to do with existing state of art software verification technologies.

CONCLUSION

Formal software verification is currently time consuming and expensive. With a continuous increase in the demand for safe and secure software, Xylem and games like it make formal software verification faster and less expensive, and therefore allow for a wider variety of software to be verified. Xylem: The Code of Plants is an effort to crowd-source software security in a way that is fun and engaging.

It is available to play exclusively on iPad (with a web version soon to be released) and can be found at the following URL:

<https://itunes.apple.com/cz/app/xylem-the-code-of-plants/id736179826?mt=8>

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