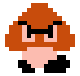
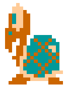
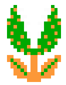
Super Mario

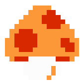
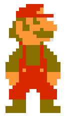
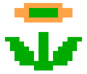
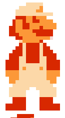
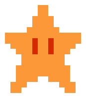
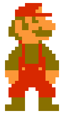
Martin Ivanov
ETH Zürich

Super Mario Crash Course

1. Goal
2. Basic Enemies

   - Goomba → 
   - Koopa Troopas → 
   - Piranha Plant → 

3. Power Ups

   - Super Mushroom →  → 
   - Fire Flower →  → 
   - Super Start →  → 
   - Coins → 

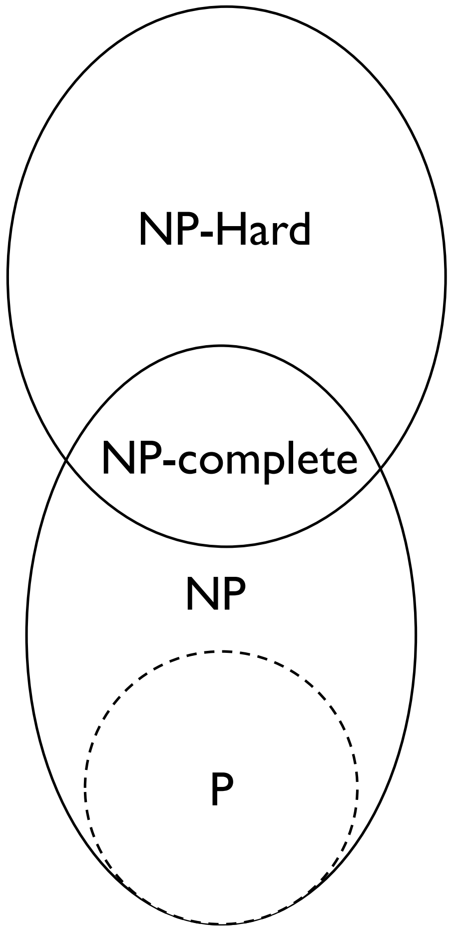
Reductions

$$Y \leq_P X$$

- Y is polynomial-time reducible to X
- X is at least as hard as Y
- if X can be solved in polynomial time, then Y can be solved in polynomial time
- if Y can not be solved in polynomial time, then X cannot be solved in polynomial time

Computational Complexity Overview

1. P
    - multiplication
    - sorting
2. NP
    - integer factoring
3. NP-complete
    - sudoku
    - satisfiability
4. NP-Hard
    - traveling salesman
5. PSPACE
    - quantified boolean formulas



Satisfiability

- **Literal**: Boolean variable or its negation x_i or $\overline{x_i}$
- **Clause**: A disjunction of literals $C_j = x_1 \vee \overline{x_2} \vee x_3$
- **Conjunction**: $C_1 \wedge C_2 \wedge C_3 \wedge C_4$
- **SAT** – given a conjunction of clauses, does it satisfy a truth assignment?
- **3-SAT** – special case of SAT where each clause contains exactly 3 literals

$$\Phi = \left(\overline{x_1} \vee x_2 \vee x_3\right) \wedge \left(x_1 \vee \overline{x_2} \vee x_3\right) \wedge \left(\overline{x_1} \vee x_2 \vee x_4\right)$$

yes instance: x_1 = true, x_2 = true, x_3 = false, x_4 = false

Gadgets

- partial instances of problem X that are used to “simulate” objects in problem Y
- used to construct reductions from one problem to another

- Start Gadget
  - can be used to initialize a specific state

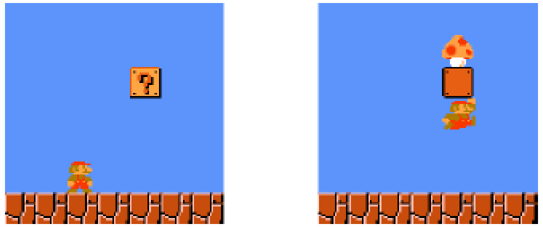


Figure 8: Left: Start gadget for Super Mario Bros. Right: The item block contains a Super Mushroom

Finish Gadget

- accessible only if the player is in the desired state

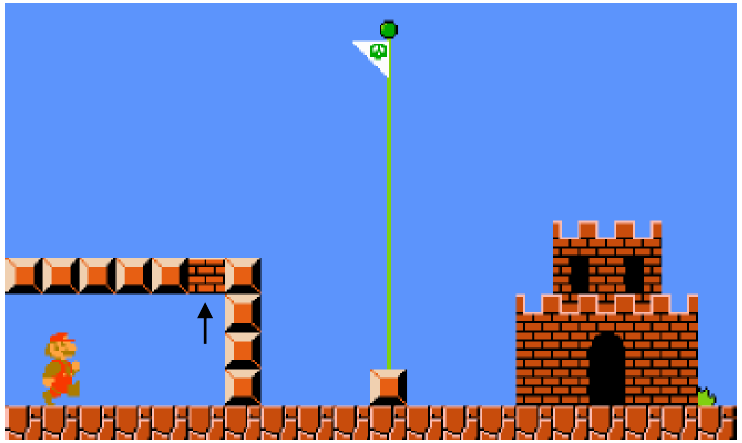
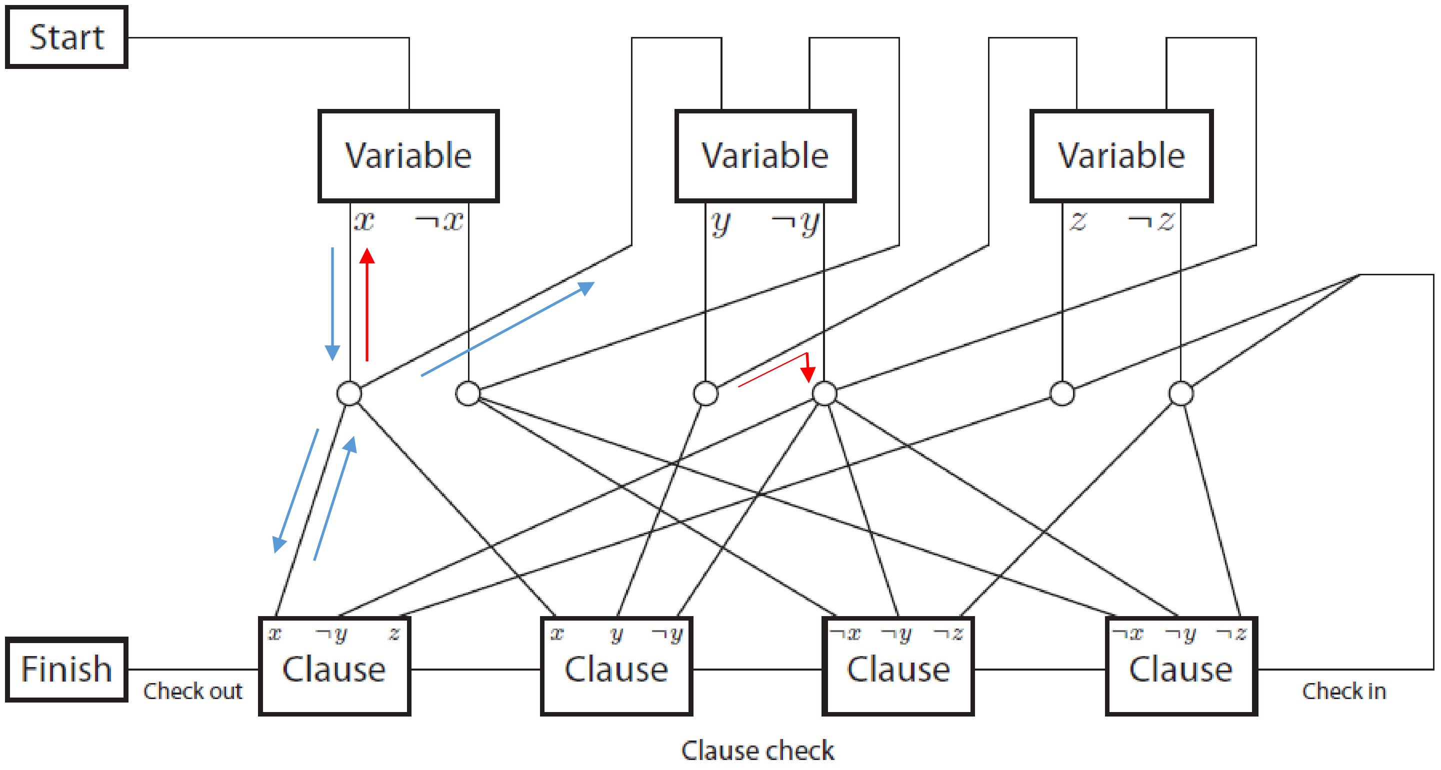


Figure 9: Finish gadget for Super Mario Bros.

Framework for NP-hardness



- The framework reduces from 3-SAT
  - allowed
  - not allowed

Variable Gadget

- must force the player to choose one of two paths
- entering from one literal does not allow traversal back into the negation of the literal

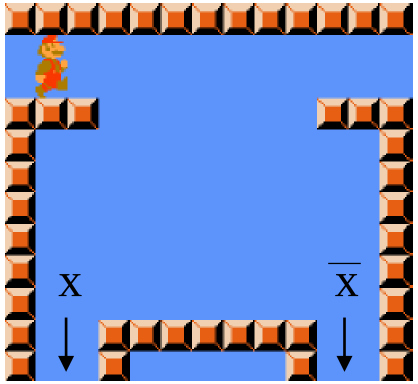


Figure 10: Variable gadget for Super Mario Bros.

Clause Gadget

- accessible from the literal paths
- the player can perform some action that "unlocks" the gadget
- the check path traverses every Clause Gadget in sequence

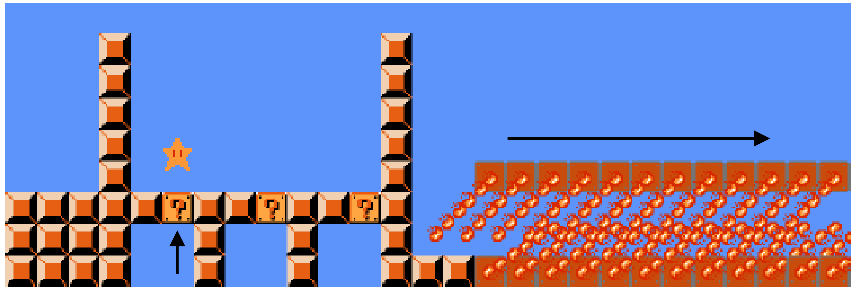


Figure 11: Clause gadget for Super Mario Bros.

Crossover Gadget

- must allow traversal via two passages that cross each other
- no leakage can occur from the vertical to the horizontal path

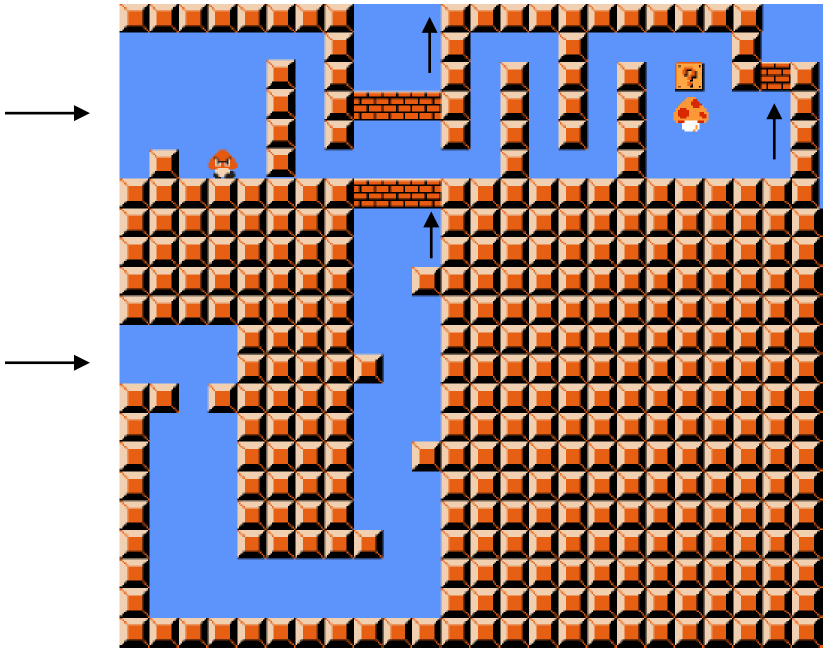


Figure 12: Crossover gadget for Super Mario Bros.

Super Mario NP-hardness

- 3-SAT $\leq_P$ MARIO

- **Theorem** *It is NP-hard to decide whether the goal is reachable from the start of a stage in generalized Super Mario Bros.*

- Related Work
  - The Legend of Zelda
  - Donkey Kong Country
  - Metroid
  - Pokemon

Nintendo Entertainment System

- 8-bit processor $\longrightarrow$ 00001111
- running at 1.79 MHz
- 2048 bytes of general purpose RAM
- fixed memory locations used for all the critical game facts

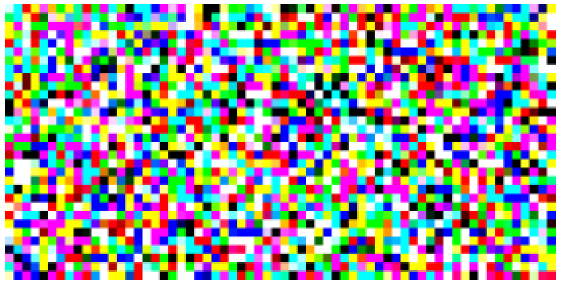


Figure 1: 2048 bytes, a 64x32 image.

Automating NES games

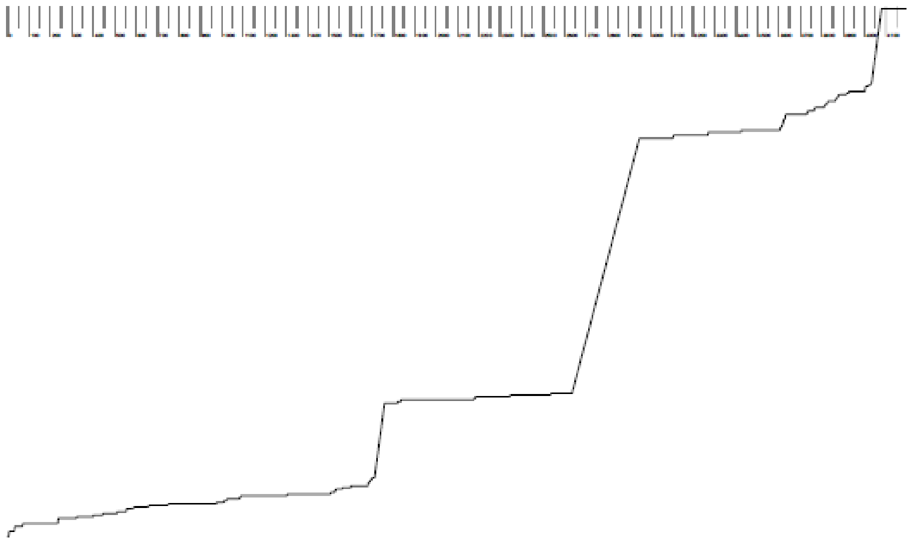
- video screen, sound effects are ignored
- notion of winning → value going up
- lexicographic order

$$a < aa < aaa < ab < aba.$$

- World 1-2 → $p=1, q=2$
- World 2-1 → $p=2, q=1$
- $(p_1,q_1) < (p_2,q_2)$ if $p_1=p_2$ and $q_1 < q_2$
- OR if $p_1 < p_2$

learnfun

- the objective function is deduced from the player's inputs
- learnfun watches you play and figures out what it means to win
- find series of byte locations in memory that go up according to the lexicographic ordering



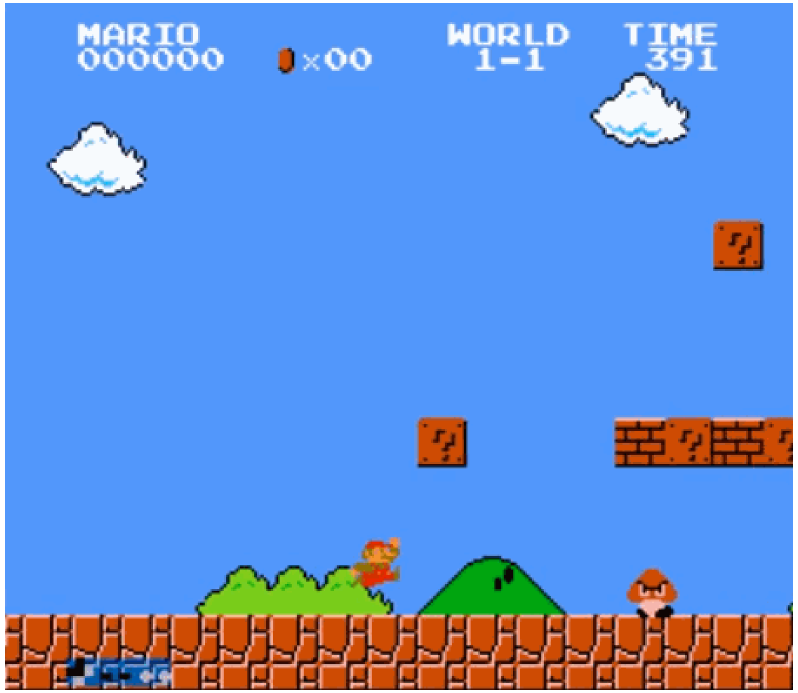
playfun

- uses the gained knowledge from learnfun to play the game
- finds the optimal sequence of inputs to satisfy the objective function

- Greedy Approach
  - search space is 2^8 different inputs, pick the best step
  - single input rarely affects your progress

Motifs

- look 10 frames into the future
- use the best scoring 10-keystroke motif
- still bad at avoiding enemies and jumps

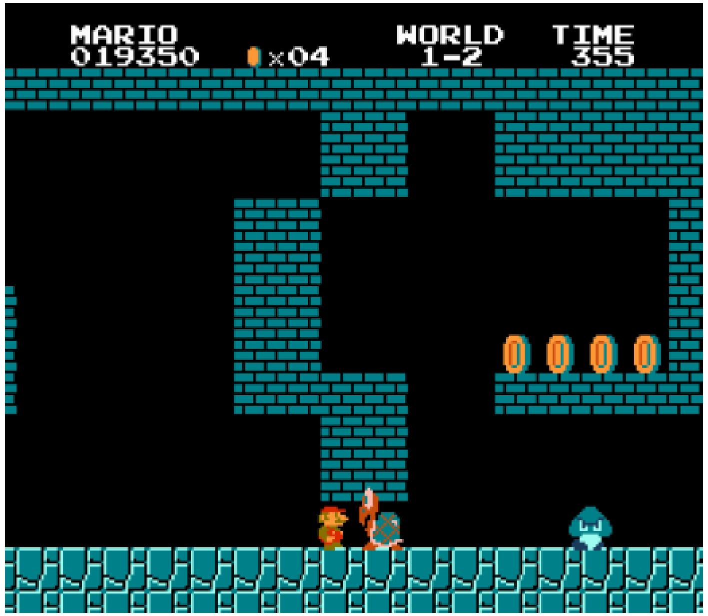


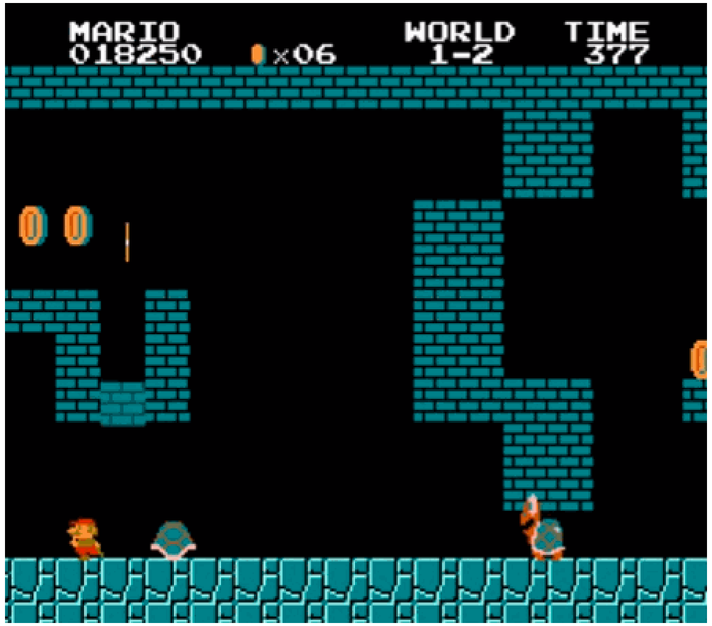
Time Travel

- pick 40 random futures (50-800 frames)
- pick (based on weight) which one to replay for the next 10 frames
- extend futures with random motifs when they become too short
- worst futures are replaced with new random futures
- reach consistency → do combinations that worked and are likely to work again

Backtracking

- local maximum
- improveme – save a checkpoint
- occasionally reset to the beginning and generate some other replacement futures
- if the original sequence is the best, backtracking does nothing





Performance

- 1 hour to calculate 1000 frames of output = 16 sec of gameplay
- most of the time is spent emulating NES code

- MARIONET
  - network version of playfun
  - utilizes multiple cores and potentially multiple computers to score futures
  - master/slave

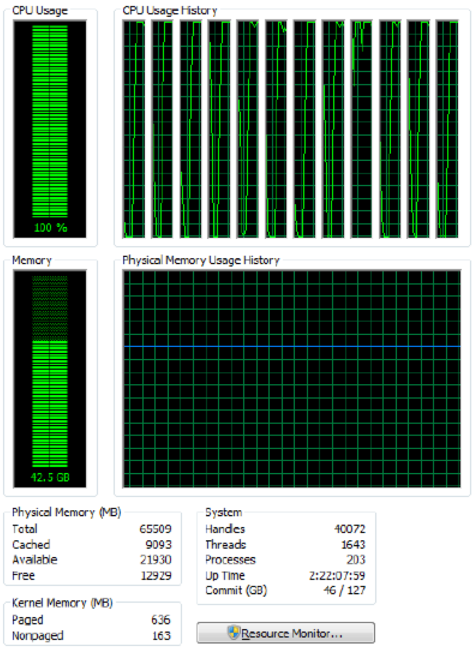


Figure 8: Utilization with 12 helpers and one master on a 6-core (12 hyperthreads) processor. Looks good. Keeps the bedroom warm.

Results

- Super Mario
- Pac-Man
- Bubble Bobble
- Tetris

Future Work

- parameter reduction
- unsupervised learning
- better backtracking
- multiple players, multiple games

Conclusion

- Nintendo Games are awesome and fun!
- can be used in serious topics
- produce real and interesting results

Thank you for your attention