Computational Intelligence for Games: General Video Game Playing

Diego Perez, Sanaz Mostaghim

diego.perez@ovgu.de, sanaz.mostaghim@ovgu.de

Magdeburg, Germany, 2014

Otto von Guericke University Magdeburg, Magdeburg, Germany

Autumn 2014

Outline

Outline

The Workshop (I)

- Professional skills:
  - Reading scientific papers.
  - Practising to present a technical talk.
  - Practising to write scientific texts.
- Practical skills:
  - Improving your programming skills.
  - Learning new algorithms.
  - Solving problems.
- Soft skills:
  - Team work.
  - Taking part in international communities and competitions.

The Workshop (II)

- Groups of 3 students:
  - A name for the group.
  - Full names of all group members.
  - A contact email.
- Each group will create 3 controllers:
  - Heuristic based controller (deadline: **12th November 2014**).
  - Reinforcement learning controller. (deadline: **26th November 2014**).
  - Nature-inspired controller (deadline: **10th December 2014**).
  - Each controller will **require**:
    - Submission of the controller to the website before the deadline.
    - 3 slides / 5 minutes presentation explaining the submitted controller.
- Each group will deliver:
  - A 15-20 minute presentation on the whole Team Project.
  - A 10-15 pages report.
- **Assessment**:
  - 1/3: Team Project Presentation.
  - 1/3: Team Project Report.
  - 1/3: Submitted controllers.

The Workshop (III)

6 important dates:

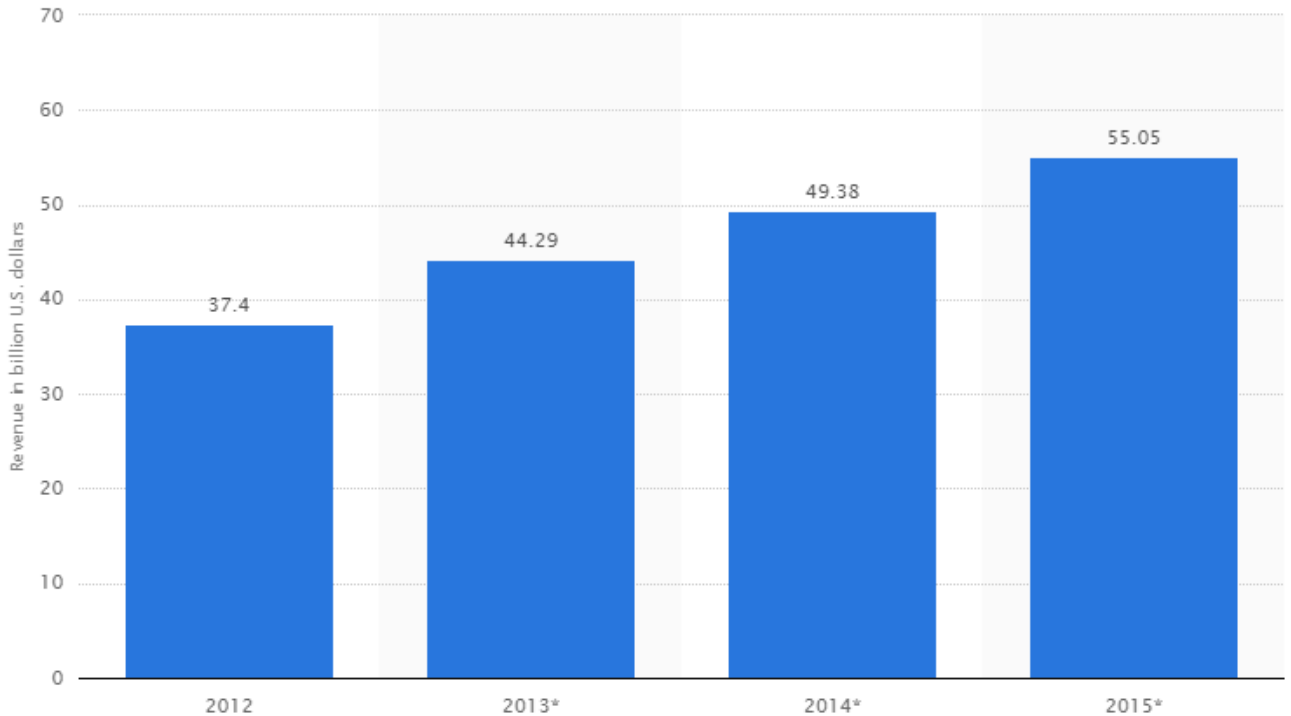
- 22nd October 2014
  - Today! First contact, introduction to the project, form groups, ...
- (+ 3 weeks) 12th November 2014
  - **Deadline** for submitting your first controller (Heuristic controller).
  - You will do a 3 slides / 5 minutes presentation about your controller.
  - We'll introduce some ideas for the next (RL) controller
- (+ 2 weeks) 26th November 2014
  - **Deadline** for submitting your second controller (RL controller).
  - You will do a 3 slides / 5 minutes presentation about your controller.
  - We'll introduce some ideas for the next (Nature-inspired) controller.
- (+ 2 weeks) 10th December 2014
  - **Deadline** for submitting your third controller (Nature inspired controller).
  - You will do a 3 slides / 5 minutes presentation about your controller.
- 21st January 2015
  - **Team Project Presentation**.
- 21st January 2015
  - **Deadline** for Team Project Report.

Outline

Why games?

Why games?

- Constantly growing industry.



Video game console hardware/software revenue worldwide from 2012 to 2015 (in billion U.S. dollars)

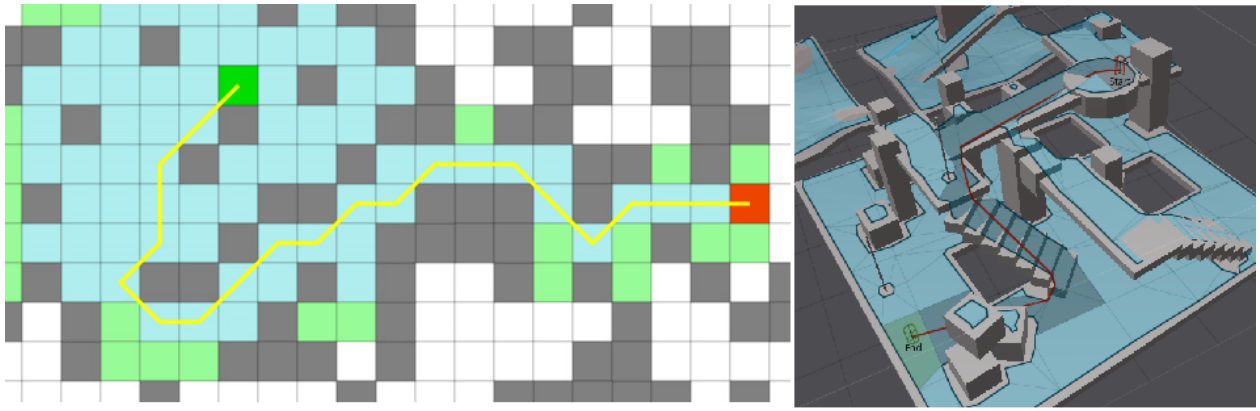
Source: Gartner, Statista 2014

Why games?

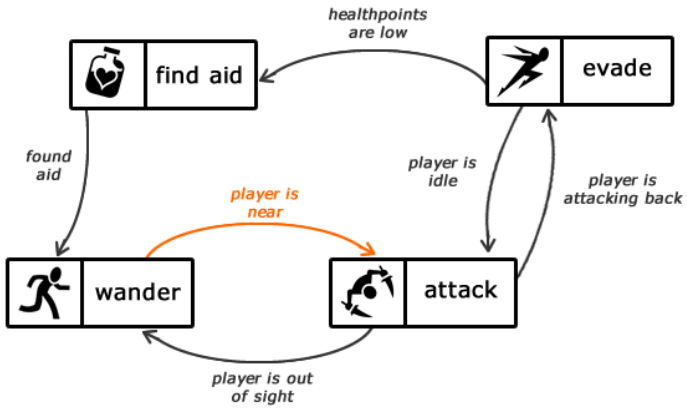
- Multiple devices.

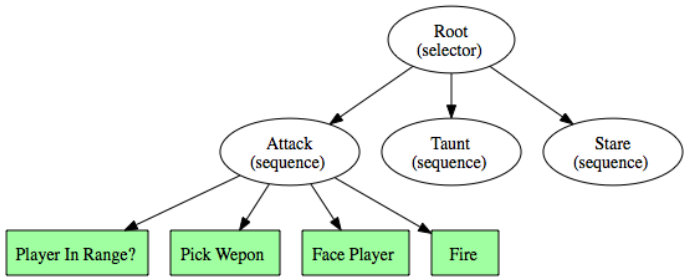
Intelligence in Games

- AI Gap between industry and academia.
- Industry: behaviour of Non Playable Characters (NPCs).
  - Path planning or pathfinding: how to move intelligently.



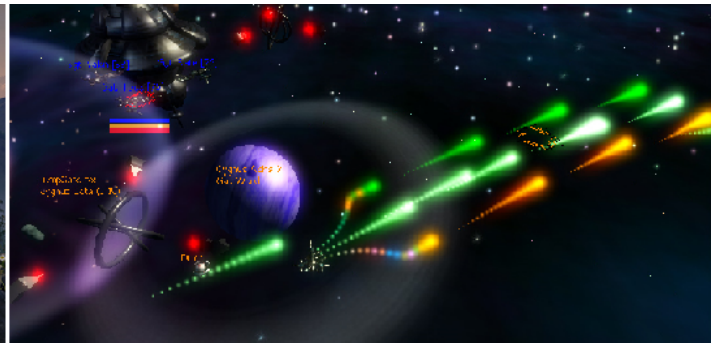
  - Proper behaviour: Finite State Machine, Behaviour Trees, Goal Action Planning.





Intelligence in Games

- Industry (cont.)
  - Procedural Content Generation (PCG)

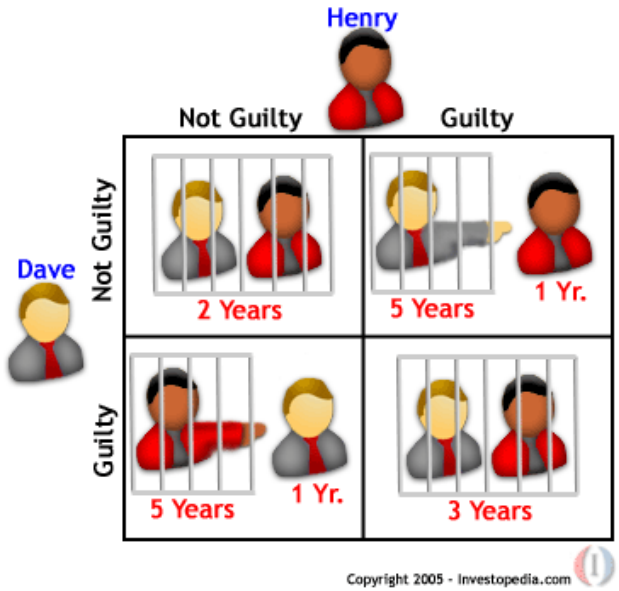



  - Player believability.


  - AI Directors, Computational Narrative, ...

Intelligence in Games

- Academia
  - Game theory
    (i.e. Prisoner's dilemma).



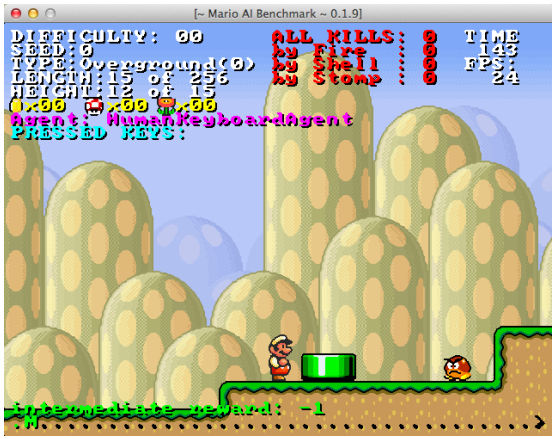
- (Player) Decision Making.
  - Board games: Chess, Checkers, Backgammon, Reversi, Go ...
  - Video (real-time) games: Racing, Real-Time Strategy, Platformer, Physics-based ...
- Procedural Content Generation (PCG): generation of games, levels, etc.
- Player experience, player modelling, game mining, BCI for games, etc.

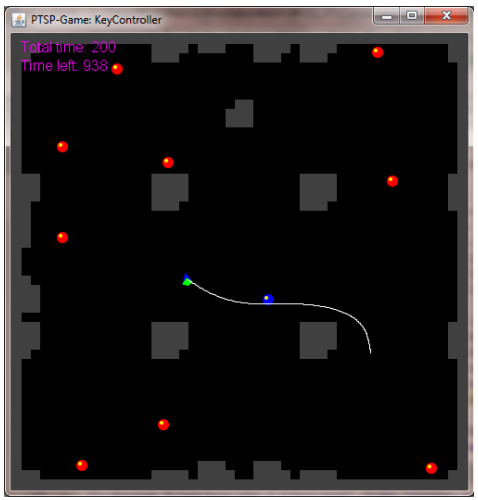
Research

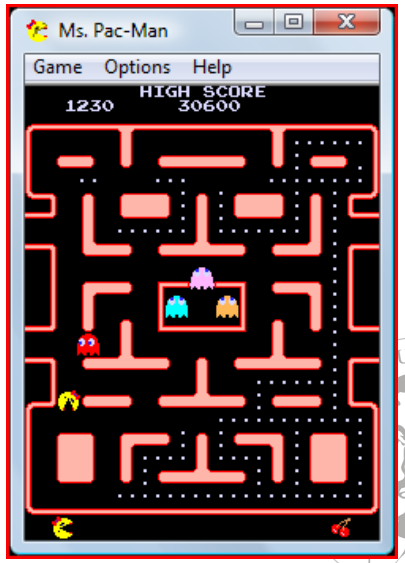
- Conferences and journals are great source of information:
  - IEEE Conference on Computational Intelligence and Games (CIG).
  - AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment (AIIDE).
  - Foundations of Digital Games (FDG).
  - Games tracks in many general AI conferences:
    - EvoGames (EvoStar).
    - Digital Entertainment and Arts (Genetic and Evolutionary Computation Conference - GECCO).
    - Computational Intelligence and Games (Congress on Evolutionary Computation - CEC).
  - IEEE Trans. on Computational Intelligence and Artificial Intelligence in Games.
  - Hindawi International Journal of Computer Games Technology.
  - IEEE Transactions on Evolutionary Computation.

Competitions

- Multiple video-game competitions in the past years.
- (the largest) subset of these is about agent decision making:







General Game Playing (GGP)

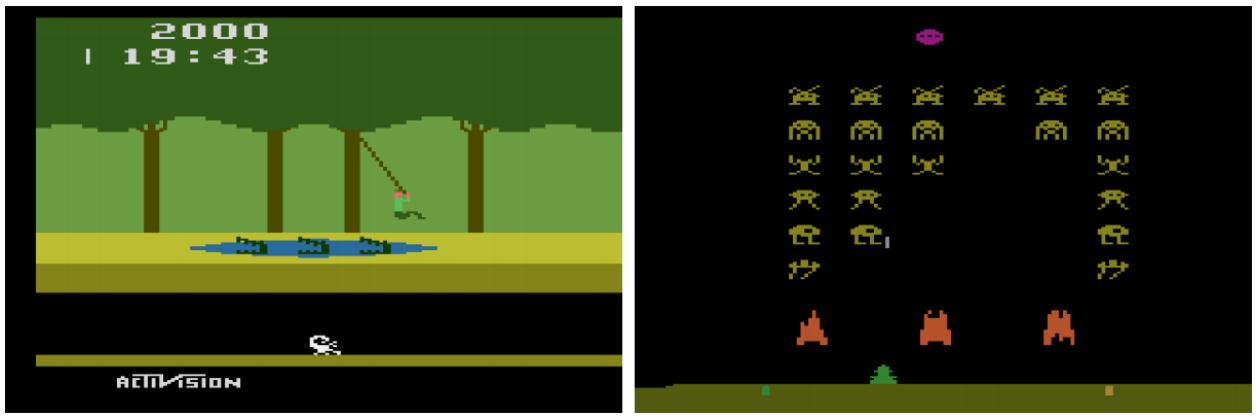
- First AIII GGP Competition, by the Stanford University Logic Group.

- $>$ 1s decision time.

General Video-Game Playing (GVGP)

- Actions performed at much higher rate ($\approx$ 40ms).

- Atari 2600 Collection:
  - Arcade Learning Environment (ALE) [1]
  - Evaluation of AI agents in domain-independent environments (55 games).



Pitfall! and Space Invaders, from [Bellemare et al., 2013]

  - RL, UCT and MCTS.
  - Contingency awareness.

General Video-Game Playing (GVGP)

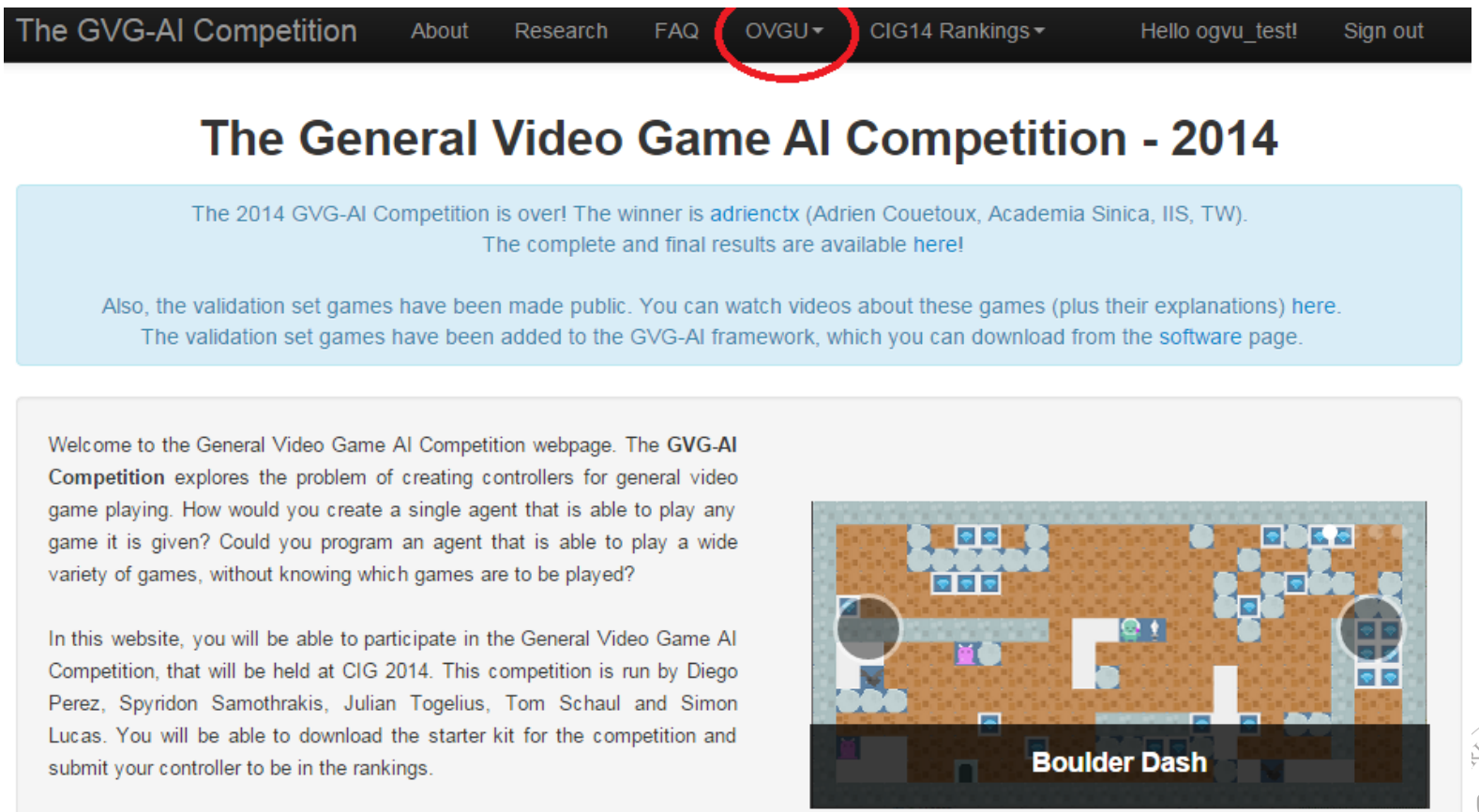
- Levine et al. (2010) [2] propose creation of new benchmark for GVGP.
- Compliments ALE in two ways:
  - Creation of games in a more general framework.
  - No screen capture analysis needed, information via encapsulated objects.

- Video Game Description Language (VGDL) [3].
  - Benchmark for learning and planning problems.
  - Base for the GVG-AI Framework, used in this workshop and in the GVG-AI Competition.

Outline

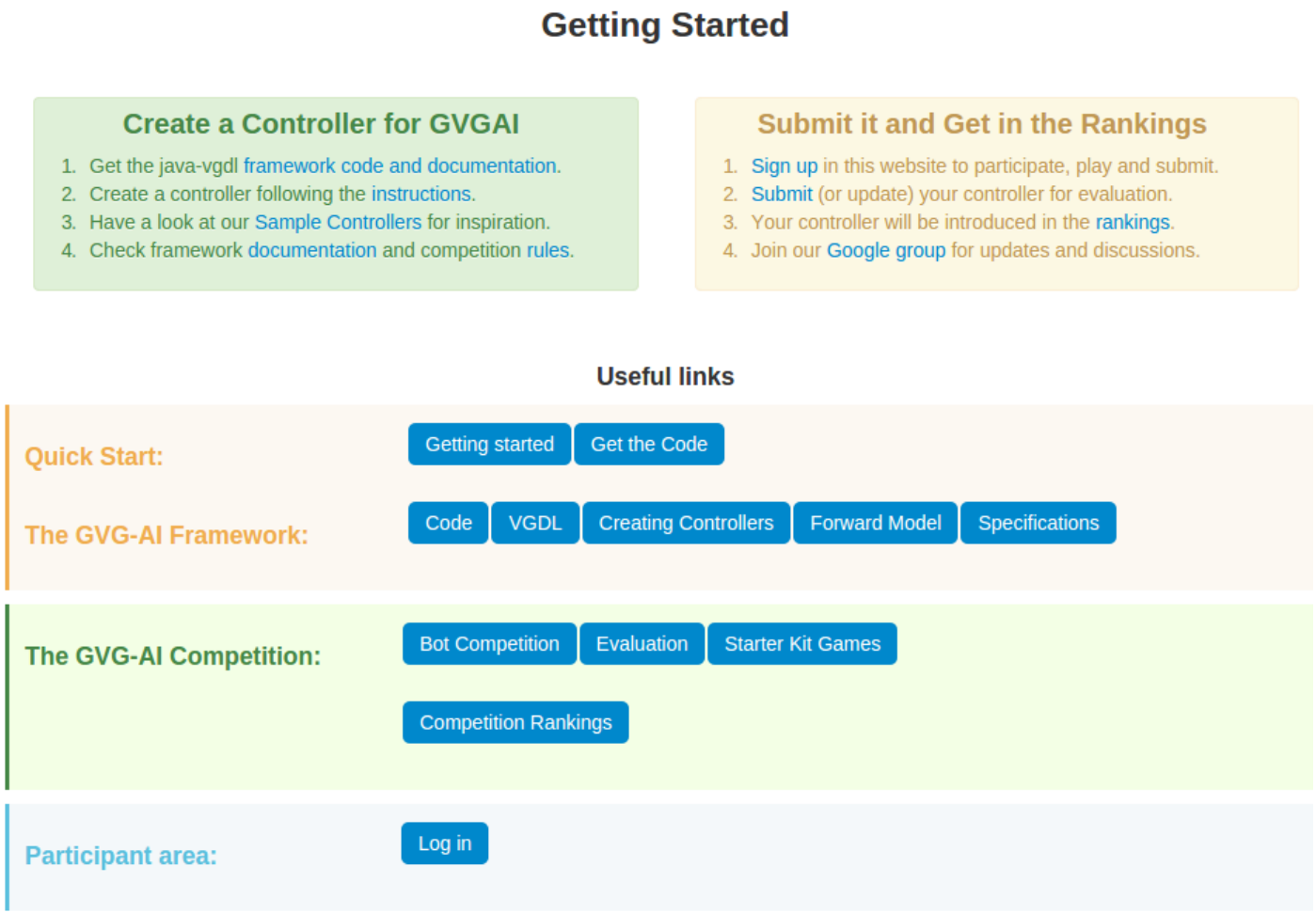
The GVGAI Website

http://www.gvgai.net

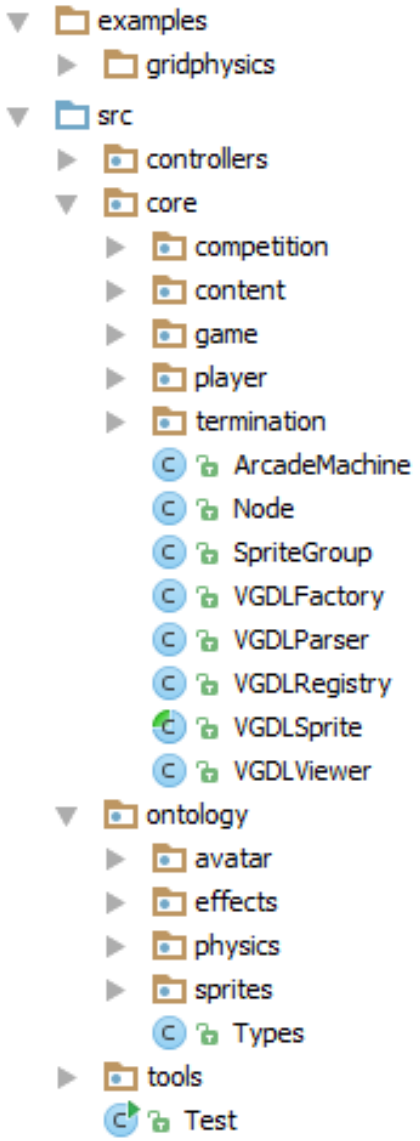


The GVGAI Website

http://www.gvgai.net



Introduction



Java, Unix.

- *examples* → *gridphysics*: Game and levels files.
- *controllers*: Sample working controllers.
- *core*: Core codebase of the framework.
- *core.competition*: Competition parameters.
- *core.content*: Game and sprite creation.
- *core.game*: Game engine, Forward Model and Observations.
- *core.player*: Abstract class for players.
- *core.termination*: Game termination conditions.
- *ontology*: Definitions for sprites, avatars, physics and events.
- *tools*: Several useful classes.
- *Test.java*: Entry point to run the framework.

VGDL - Game Definitions

```
BasicGame
    SpriteSet
        base    > Immovable    color=WHITE img=base
        avatar  > FlakAvatar   stype=sam
        missile > Missile
            sam  > orientation=UP    color=BLUE singleton=True img=spaceship
            bomb > orientation=DOWN  color=RED  speed=0.5 img=bomb
        alien   > Bomber       stype=bomb   prob=0.01  cooldown=3 speed=0.8 img=alien
        portal  >
            portalSlow  > SpawnPoint   stype=alien  cooldown=16   total=20 img=portal
            portalFast  > SpawnPoint   stype=alien  cooldown=12   total=20 img=portal

    LevelMapping
        0 > base
        1 > portalSlow
        2 > portalFast

    TerminationSet
        SpriteCounter      stype=avatar               limit=0 win=False
        MultiSpriteCounter stype1=portal stype2=alien limit=0 win=True

    InteractionSet
        avatar  EOS  > stepBack
        alien   EOS  > turnAround
        missile EOS  > killSprite
        missile base > killSprite
        base bomb > killSprite
        base sam > killSprite scoreChange=1
        base   alien > killSprite
        avatar alien > killSprite scoreChange=-1
        avatar bomb  > killSprite scoreChange=-1
        alien  sam   > killSprite scoreChange=2
```

VGDL - Level Definitions

```
1  wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
2  w                                  w
3  w1                                 w
4  w000                               w
5  w000                               w
6  w                                  w
7  w                                  w
8  w                                  w
9  w                                  w
10 w     000       000000      000     w
11 w    00000     00000000    00000    w
12 w    0   0     00    00    00000    w
13 w                  A               w
14 wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
```

A Sample (random) controller

```java
package random; //The package name is the same as the username in the web.

public class Agent extends AbstractPlayer {

    protected Random randomGenerator;

    //Constructor. It must return in 1 second maximum.
    public Agent(StateObservation so, ElapsedCpuTimer elapsedTimer)
    {
        randomGenerator = new Random();
    }

    //Act function. Called every game step, it must return an action in 40 ms maximum.
    public Types.ACTIONS act(StateObservation stateObs, ElapsedCpuTimer elapsedTimer) {

        //Get the available actions in this game.
        ArrayList<Types.ACTIONS> actions = stateObs.getAvailableActions();

        //Determine an index randomly and get the action to return.
        int index = randomGenerator.nextInt(actions.size());
        Types.ACTIONS action = actions.get(index);

        //Return the action.
        return action;
    }
}
```

StateObservation (I)

- Allows the agent to query the state of the game:
  - StateObservation.getGameScore();
  - StateObservation.getGameTick();
  - StateObservation.getGameWinner();
  - StateObservation.isGameOver();
  - StateObservation.getWorldDimension()
- ...the state of the avatar:
  - StateObservation.getAvatarPosition();
  - StateObservation.getAvatarSpeed();
  - StateObservation.getAvatarOrientation();
  - StateObservation.getAvatarResources();
- ...the available actions in the game:
  - StateObservation.getAvailableActions();
- ...the history of events (collisions) in the game:
  - StateObservation.getEventsHistory();

StateObservation (II)

- . . . *Observations* in the game:
  - StateObservation.getObservationGrid();
  - StateObservation.getNPCPositions(position?);
  - StateObservation.getImmovablePositions(position?);
  - StateObservation.getMovablePositions(position?);
  - StateObservation.getResourcesPositions(position?);
  - StateObservation.getPortalsPositions(position?);
  - StateObservation.getFromAvatarSpritesPositions(position?);

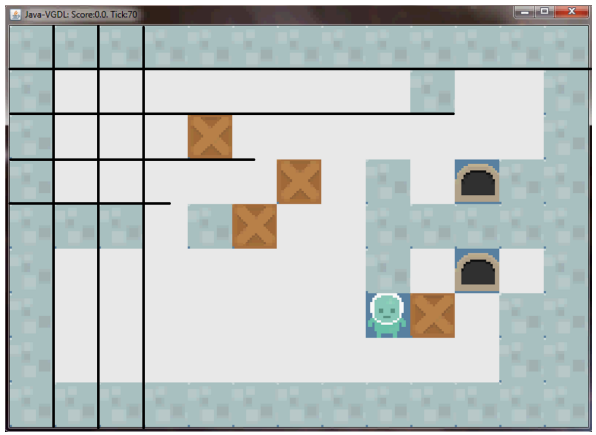
What is an *Observation*? It is an object that contains:

- *int itype*: Type of sprite of this observation.
- *int category*: Category of this observation (static, resource, npc, etc.).
- *int obsID*: Unique ID for this observation.
- *Vector2 position*: Position of the observation.
- *Vector2 reference*: Reference (pivot) position.
- *double sqDist*: Distance from this observation to the reference.

StateObservation (III)

In *StateObservation*:

```
1 ArrayList<Observation>[][] getObservationGrid();
```



- Bi-dimensional array, matching the level grid.
- Each ArrayList contains list of Observations in that position.

```
1 ArrayList<Observation>[] getNPCPositions();
2 ArrayList<Observation>[] getNPCPositions(Vector2d reference);
```

- Returns a list of observations of NPC in the game.
- As there can be NPCs of different type, each entry in the array corresponds to a sprite type.
- Every ArrayList contains a list of objects of type Observation.
- If "reference" is given, Observations are sorted by distance to the reference's position.

The Forward Model

Also, in *StateObservation*:

```
1 StateObservation copy();
```

- Create a copy of the *StateObservation* object.

```
1 void advance(Types.ACTIONS action);
```

- Advances the StateObservation object, applying the *action* supplied.
- Allows to simulate the effects of applying actions.
- The StateObservation updates itself to reflect the next state.
- **Important:** The games are stochastic in nature!
  - The next state must be considered as a *possible* future state when applying a certain action.
  - The agent has the responsibility to deal with these *inaccuracies*.

Outline

Our GVG Contest - www.gvgai.net - Sets and steps

- There are three different sets where you can submit your controller.
- You must submit to all of them before each upcoming deadline.
  - Two sets are for training, and their games are included in the framework.
  - The third set is for test, and you won't know the games at all!

1. Sign up (one account per controller).
   - eg: GROUPNAME_HR, GROUPNAME_RL, GROUPNAME_NI
   - For now, just create one account with the username GROUPNAME_HR.
2. Get framework from `http://www.gvgai.net/software.php`.
3. Submit your source code to `http://www.gvgai.net/submit_gvg_ovgu.php`.
   - **Important:** See the instructions on that page:
   - Your agent must be implemented in a file called *Agent.java*.
   - The Java package where it is contained must be **the same as your username**.
   - Your controller will be compiled and executed automatically.
4. Check the rankings:
   - Training Set 1: `http://www.gvgai.net/gvg_rankings_ovgu_t1.php`.
   - Training Set 2: `http://www.gvgai.net/gvg_rankings_ovgu_t2.php`.
   - Test Set: `http://www.gvgai.net/gvg_rankings_ovgu_test.php`.

Our GVG Contest - www.gvgai.net - Rankings

- Evaluation in 10 games, 5 levels per game, 1 times.
- Three results are considered per game, in this order:
  - Number of victories (↑).
  - Total score (↑).
  - Time spent (↓).
- All entries ranked and awarded with points: $25, 18, 15, 12, 10, 8, 6, 4, 2, 1$.
- Final rankings by adding all points across all games.

Game	Username	Country	Points	Winner	Score	Timesteps
Chase	IdealStandard	Switzerland	25	5	50	349
Chase	JinJerry	Taiwan, ROC	18	5	49	665
Chase	adrienctx	Taiwan, ROC	15	5	48	2166
Chase	FastEvoMCTS	United Kingdom	12	4	48	2367
Chase	MnMCTS	United Kingdom	10	4	47	2652
Chase	MMbot	Korea, Republic of	8	4	39	5610
Chase	sampleMCTS	United Kingdom	6	3	37	6196
Chase	sampleGA	United Kingdom	4	3	24	8996
Chase	ssamot	United Kingdom	2	2	37	7305
Chase	T2Thompson	United Kingdom	1	2	23	5686
Chase	random	United Kingdom	0	1	22	4910
Chase	Normal_MCTS	Korea, Republic of	0	1	20	8820

Our GVG Contest - 12/11/2014 - Groups

12/11/2014 - HR rankings and groups of the contest:

Team TopBug

Martin Hünermund and Jens Dieskau.
TR1: 1^{st}, TR2: 1^{st}, TEST: 1^{st}.

Team emergence

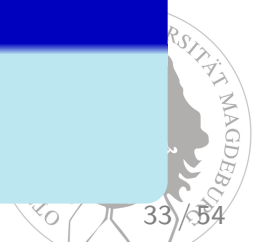
Julian Blank and Frederick Sander.
TR1: 2^{nd}, TR2: 2^{nd}, TEST: 2^{nd}.

Team Taccocat

Erik Schondorff, Xenija Neufeld, Florian Uhde.
TR1: 4^{th}, TR2: 4^{th} TEST: 3^{rd}.

Team xixue

Shengnan Chen, Vishnu Unnikrishnan and Shadi Akhras
TR1: 3^{rd}, TR2: 3^{rd}, TEST: 4^{th}.



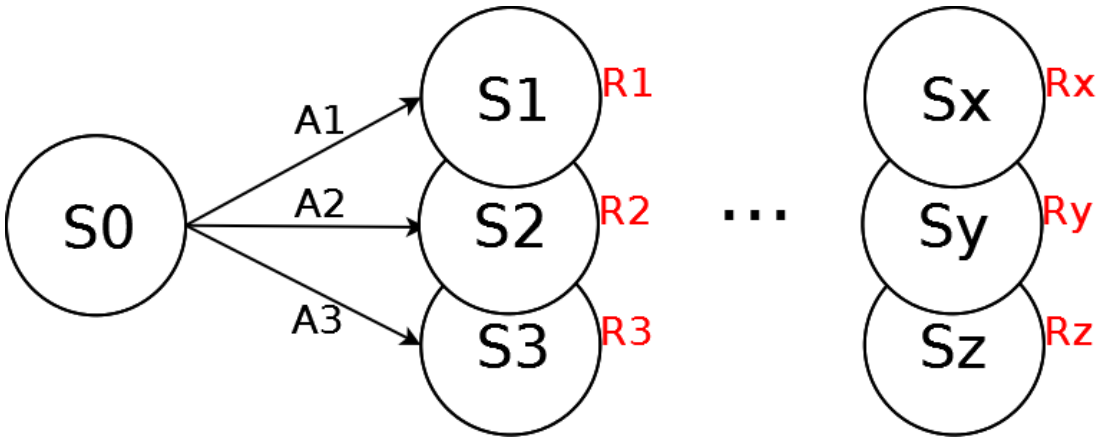
Outline

Agent Decision Making

- How to make a decision?

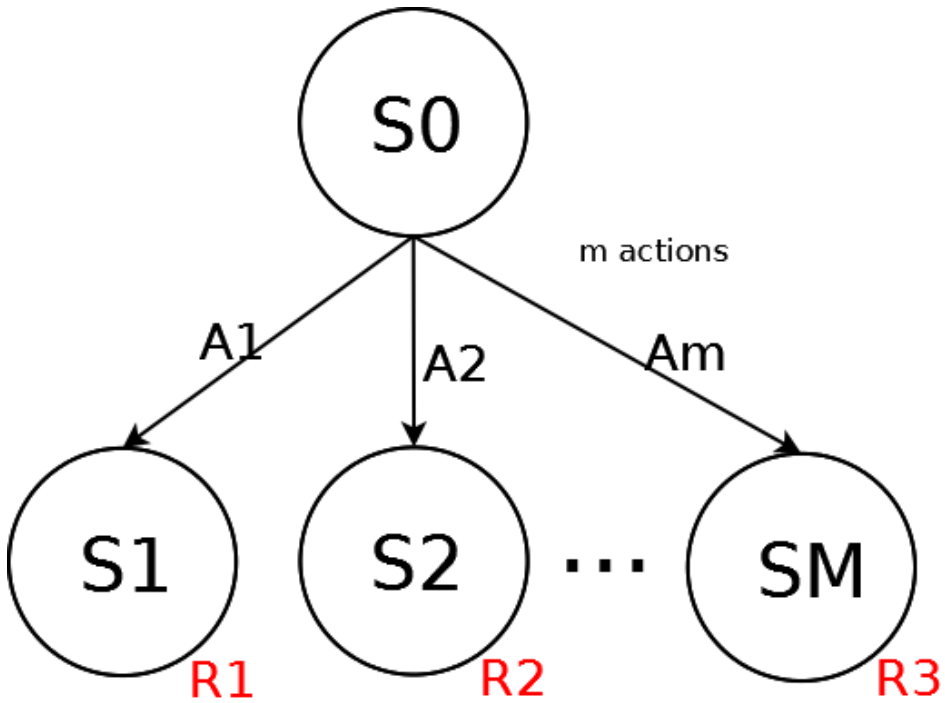
A Markov Decision Process is a tuple $< S, A, P, R, \gamma >$

- S: Finite set of all possible states of the game.
- A: Finite set of all possible actions in the game.
- P: A State Transition Probability Matrix $P^a_{ss'} = \mathbb{P}[s'|s, a]$.
- R: A Reward Function, $R^a_s = \mathbb{E}[r|s, a]$.
- γ: A discount factor $\gamma \in [0, 1]$.



One Step Look Ahead

- Try them all, pick the action with the highest reward.



One Step Look Ahead

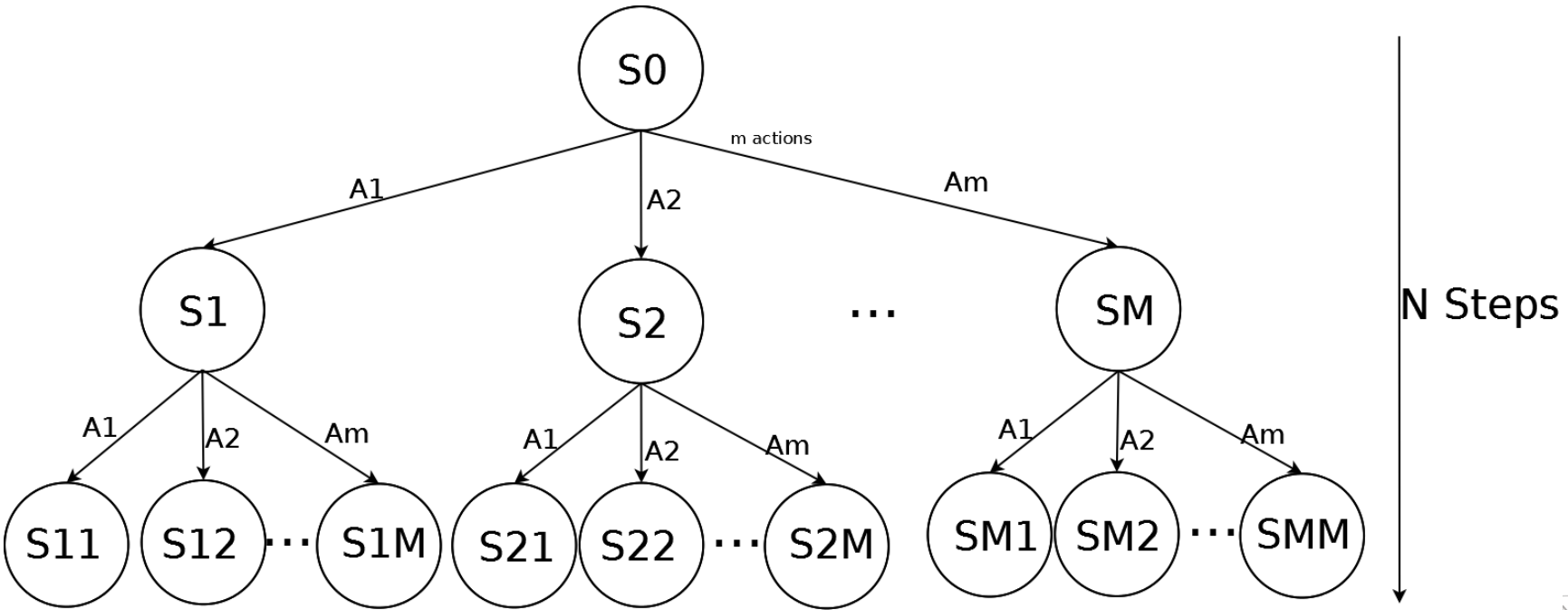
```
public Types.ACTIONS act(StateObservation stateObs, ElapsedCpuTimer elapsedTimer) {

    Types.ACTIONS bestAction = null;
    double maxQ = Double.NEGATIVE_INFINITY;
    SimpleStateHeuristic heuristic =  new SimpleStateHeuristic(stateObs);
    for (Types.ACTIONS action : stateObs.getAvailableActions()) {

        StateObservation stCopy = stateObs.copy();
        stCopy.advance(action);
        double Q = heuristic.evaluateState(stCopy);

        if (Q > maxQ) {
            maxQ = Q;
            bestAction = action;
        }
    }

    return bestAction;
}
```

A Simple Value Function

```
public double evaluateState(StateObservation a_gameState) {

    boolean gameOver = a_gameState.isGameOver();
    Types.WINNER win = a_gameState.getGameWinner();
    double rawScore = a_gameState.getGameScore();

    if(gameOver && win == Types.WINNER.PLAYER_LOSES)
        return HUGE_NEGATIVE;

    if(gameOver && win == Types.WINNER.PLAYER_WINS)
        return HUGE_POSITIVE;

    return rawScore;
}
```

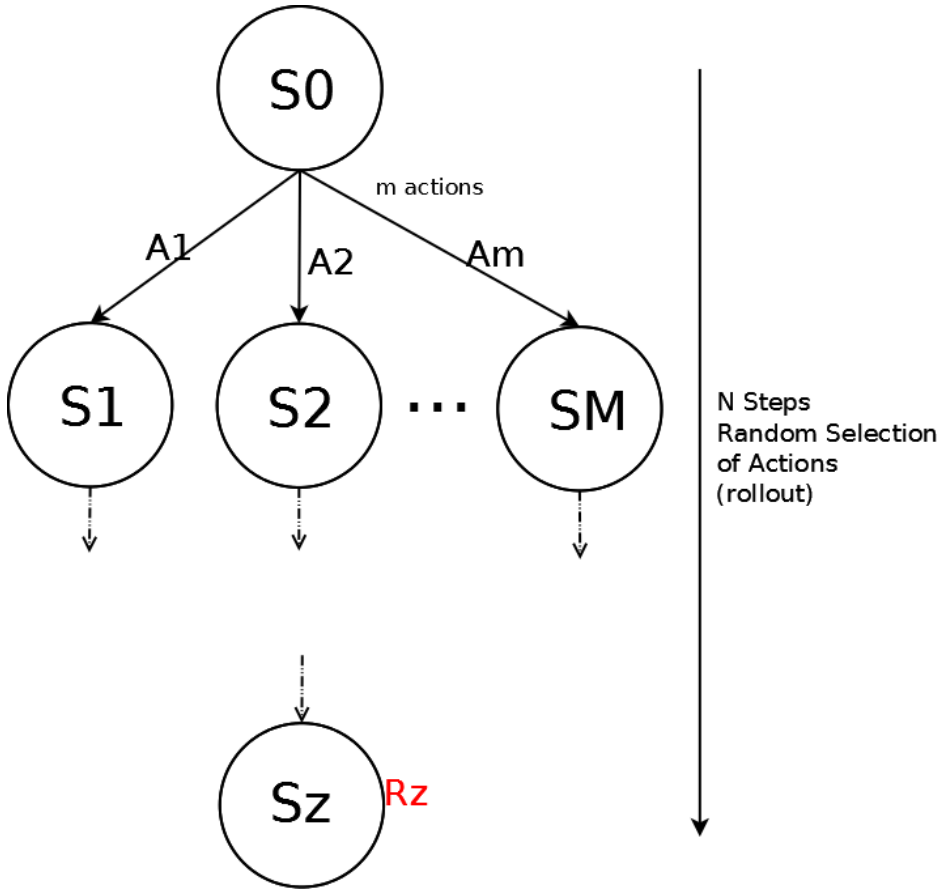
N-Step Look Ahead

- Build a tree: search exhaustively N steps in the future.
- Pick the action that leads to the highest reward after these N steps.



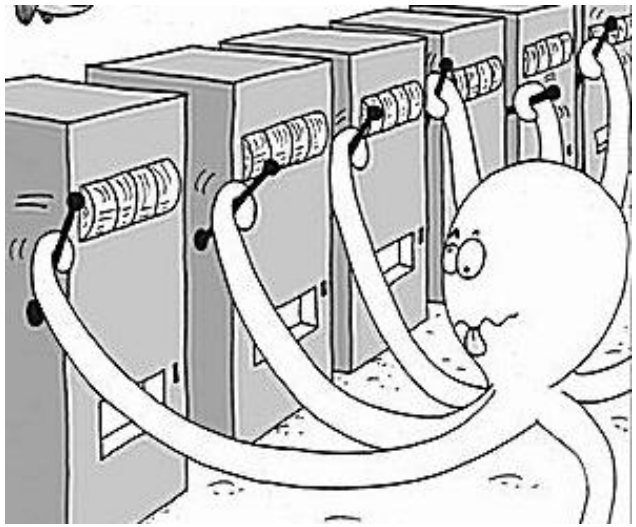
Flat Monte Carlo (Flat MC)

- Iteratively, apply N consecutive actions picked randomly.
- Pick the action that leads to:
  - the highest reward after N steps.
  - the highest **average** reward after N steps, etc.



Upper Confidence Bound for Trees (UCT) (I)

The Multi-Armed Bandit Problem.



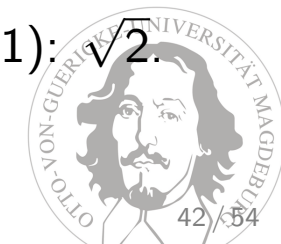
- Set of unknown distributions $B = \{R_1, R_2, \ldots, R_k\}$ of rewards.
- Played iteratively, during H action selections.
- Mean values of these reward distributions: $\{\mu_1, \mu_2, \ldots, \mu_k\}$
- The goal is to maximize the sum of rewards (minimizing the loss).
- Each action is pulling one lever. How do you choose?
  - Play randomly.
  - Epsilon-greedy strategies.
  - Many more ...

Upper Confidence Bound for Trees (UCT) (II)

- Balance exploration and exploitation.
- An example: UCB1.

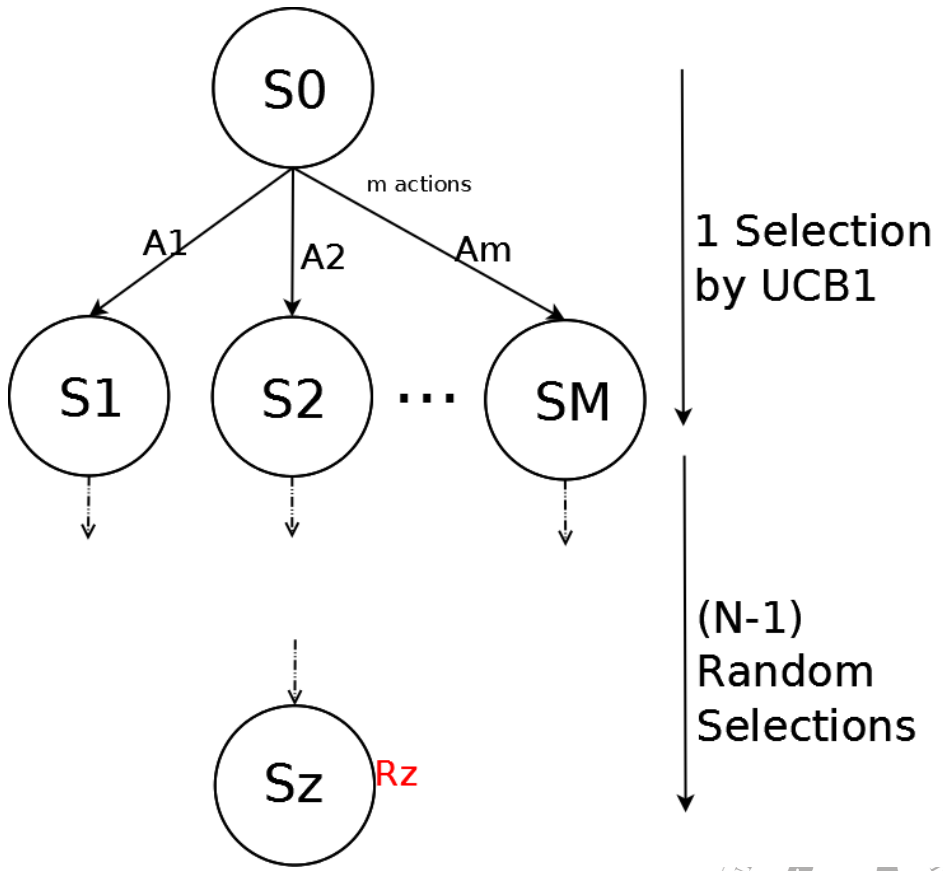
$$a^* = \arg\max_{a \in A(s)} \left\{ Q(s,a) + C\sqrt{\frac{\ln N(s)}{N(s,a)}} \right\}$$

- $Q(s,a)$: Average of rewards after taking action a from state s.
- $N(s)$: Times the state s has been visited.
- $N(s,a)$: Times the action a has been picked from state s.
- C: Balances exploitation (Q) and exploration ($\sqrt{\ldots}$) terms.
  - Application dependant.
  - Typical value, for single player games with rewards normalized in $(0,1)$: $\sqrt{2}$.



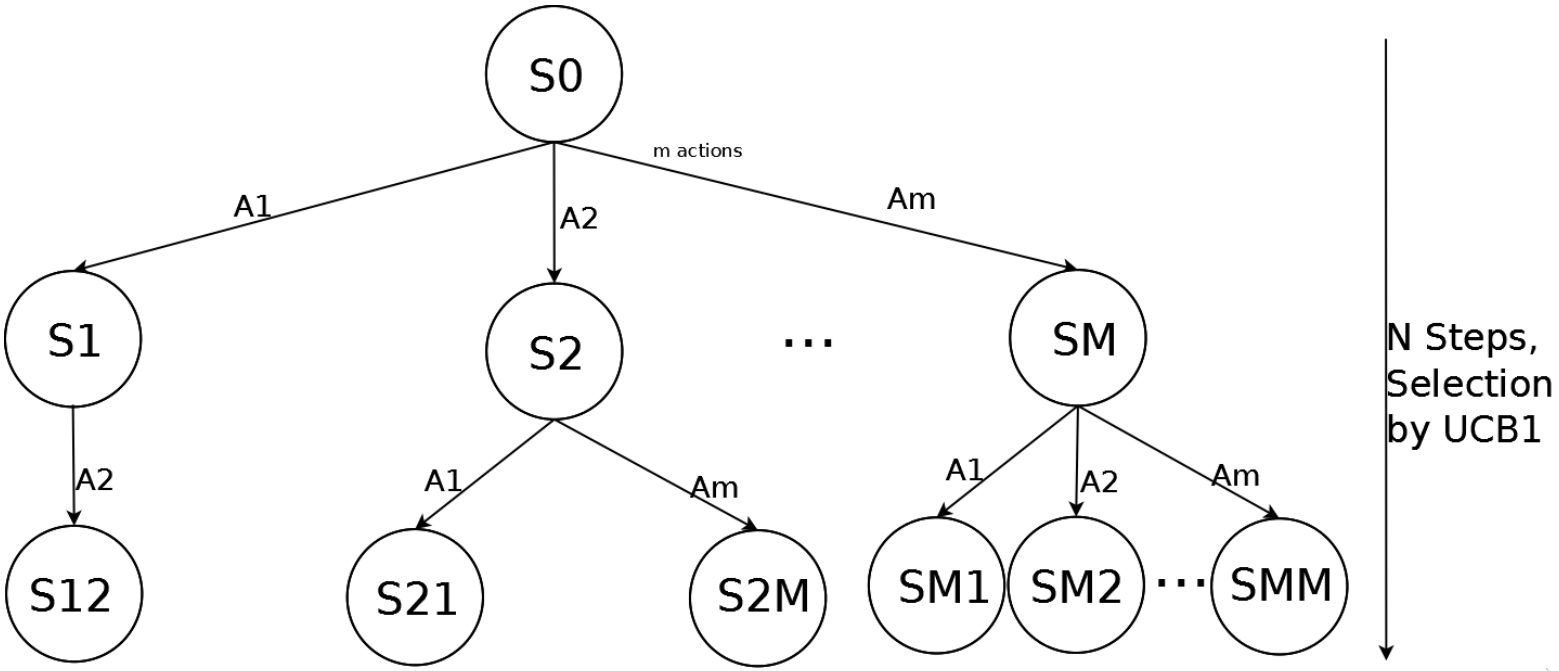
Flat UCB

- Use UCB1 to select action from the root node (or current state).
- Pick $(N-1)$ actions at random.
- Repeat iteratively, return action with:
  - the highest reward after N steps.
  - the highest **average** reward after 1 step $(Q(s,a))$.
  - the most visited node after 1 step (highest a for $N(s,a)$).
  - the highest UCB1 value after 1 step, etc.

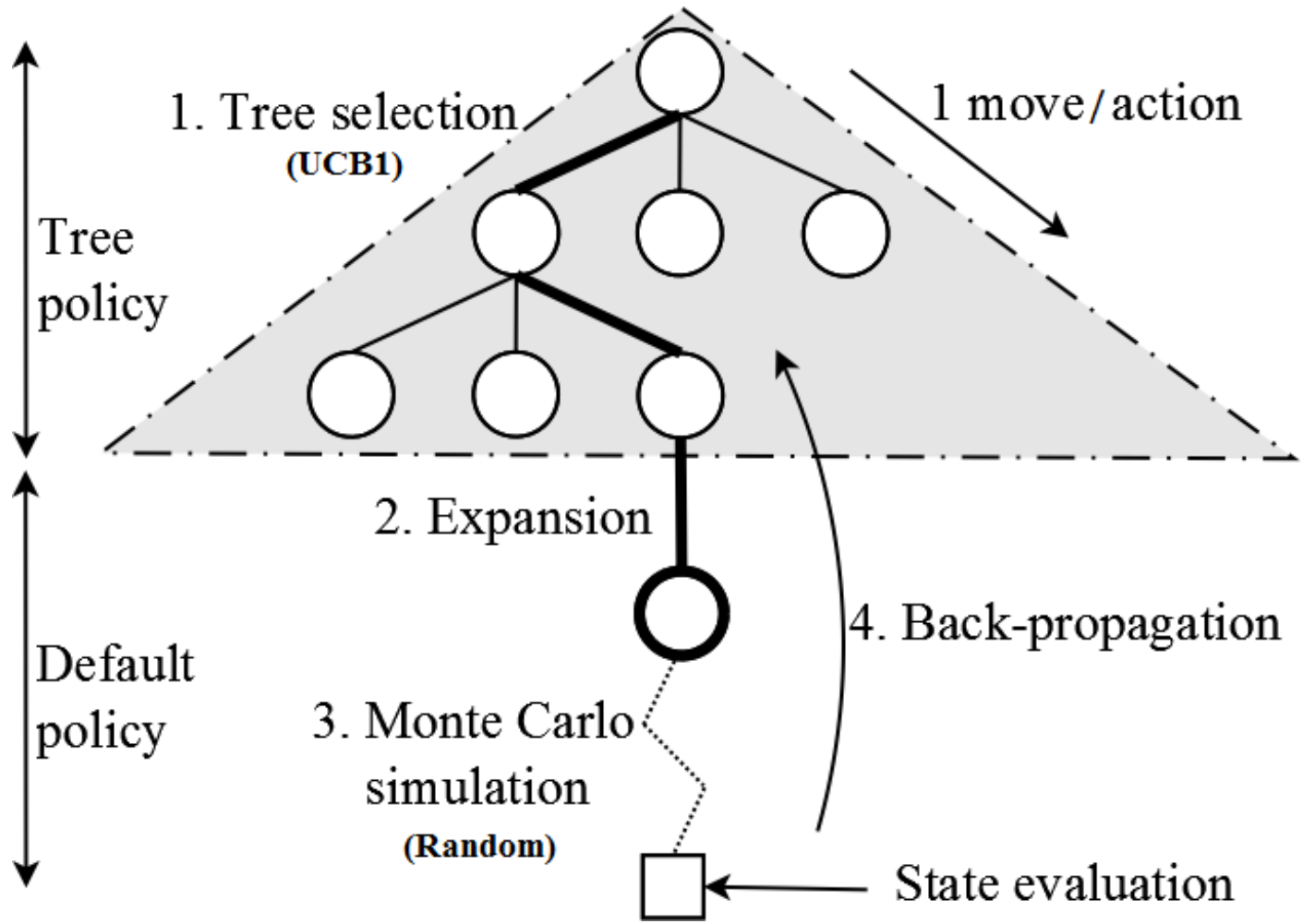


Building a tree with UCB1

- Build a tree: search N steps in the future.
- The search is **not** exhaustive: tree grows asymmetrically.
- Repeat iteratively, return action with:
  - the highest reward after N steps.
  - the highest **average** reward after 1 step ($Q(s, a)$).
  - the most visited node after 1 step (highest a for $N(s, a)$).
  - the highest UCB1 value after 1 step, etc.



Monte Carlo Tree Search (MCTS)



Open vs. Closed loop control

- Our methods must face the challenge of stochasticity.
  - If MCTS stores the nodes in the tree: *closed loop*.
  - This means that, once the node is added, the state is unchanged.
  - Quite possibly, this might lead to inaccuracies ($P^a_{ss'} = \mathbb{P}[s'|s, a]$).
  - It is possible to do statistics on the actions (*open loop*).
- In Closed loop control:
  - Intermediate states are stored during the algorithm.
  - Every new action is applied over a (previously) stored state.
  - In MCTS, each node stores a state, within the node statistics.
- In Open loop control:
  - Intermediate states are **not** stored during the algorithm.
  - Every new action is applied over the state reached at that moment.
  - In MCTS, each node stores only the statistics, not the store.
  - In other words, each decision in the tree uses the Forward Model.

- **Summarizing:**
  - Closed loop control works on a *sequence of (state,action) pairs*.
  - Open loop control works on a *sequence of actions*.

Evolutionary algorithms (EA)

"Traditional" Evolutionary Algorithms:

- Population of individuals, each one is a solution to a given problem.
- Each individual is evaluated in the problem, and assigned a *fitness*.
- The *fitness* indicates *how good* this solution is to the given problem.
- Population evolves during several generations, creating new individuals by recombination and mutation of individuals in the population.
- Elitism: population does not discard the best individual(s) of a generation.

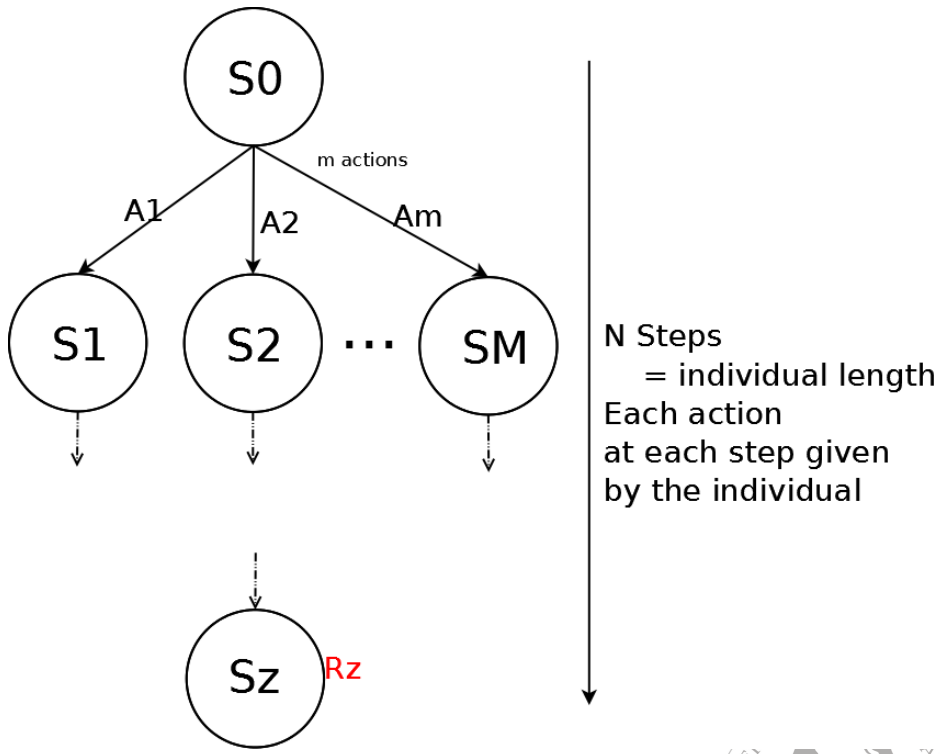
Possibility, following a "classical" approach for General Video Game Playing:

- Each individual is a player: determines how action decisions are made.
- This is *offline* training:
  - EA determines the best agent first.
  - The *submitted* agent does not use *online* evolution.

Rolling Horizon Evolutionary Algorithms (RH-EA)

No *offline training*, evolution is use *online*, while playing the game.

- Each individual is a **sequence of actions** to apply from the current state: it is **open loop** control.
- Fitness: Evaluation of the state reached after applying the sequence of actions.
- Within the real-time constraints, the RH-EA evolves the best sequence of actions.
- Evolve the population normally: mutation, crossover, elitism, etc.
- When the process is over, apply first action of the best individual.
- *SampleGA* Sample Controller.



Some additional ideas

Other things that can be included:

- Reducing the search space:
  - Macro-actions.
  - Avoid consecutive opposite actions.
  - Avoid actions that do not change the state.
- Knowledge discovery:
  - Use the states visited during the simulations to discover game features.
    - i.e.: what events (collisions) seem to award points?
    - i.e.: what events make the avatar win/lose the game?
  - Maximize exploration:
    - i.e.: reward states that visit newly found positions.
    - i.e.: reward states with events rarely seen.
  - Incorporate this into the state evaluation function.
- New ideas?
  - Neural Networks.
  - Particle Swarm Optimization.
  - Ant Colony Optimization.

TeamProject Report - Due 21st January 2015

- Two templates provided, see TeamProject website: Word and LaTeX.
- 15-20 pages.
- **Suggested** structure:
  - Introduction.
  - Literature Review.
  - Background.
  - Techniques Implemented.
  - Experimental Study.
  - Conclusions and Future Work.
  - References.
- Results to report:
  - On the three controllers implemented.
    - Comparisons **must** be as fair as possible: state evaluation, look-ahead depth, etc.
    - Make clear this in the report. If something cannot be made equal, explain why.
  - Results in the final rankings on the website (you can keep submitting!).
  - **More importantly:** results comparing your three controllers.
    - Victory rate, score, time steps.

On 21st January 2015 . . . TeamProject Presentations

- Each team gives a 15-20 minutes presentation.
- Describe all controllers implemented.
  - Brief description of the core techniques used (MCTS, EA?).
  - Explain how they have been adapted for GVGAI.
- Report results.
- Development process:
  - What things worked? What things didn't work? Was something surprising (in either way)?
  - Evolution of the State Evaluation function: how has it changed from controller to controller.
- Main problems and difficulties found.
- Conclusions: main findings and lessons learned.
- Future work.

- Ahh... and make it interesting! (= fun).

Marking breakdown

- 40% Final Presentation.
  - Clarity, time, all points above, etc.
- 40% Final Report.
  - Clarity, explanations, references, all points above, etc.
- 20% Code.
  - Quality: re-usability, clarity, comments, efficiency, etc.

Some Readings

MCTS Survey:

1. Cameron Browne, Edward Powley, Daniel Whitehouse, Simon Lucas, Peter Cowling, Philipp Rohlfshagen, Stephen Tavener, Diego Perez, Spyridon Samothrakis and Simon Colton, **A Survey of Monte Carlo Tree Search Methods**, *IEEE Transactions on Computational Intelligence and AI in Games* (2012), pp. Vol. 4:1 143-191.

About MCTS for GVG and other real-time games. Also macro-actions:

1. Diego Perez, Spyridon Samothrakis and Simon M. Lucas, **Knowledge-based Fast Evolutionary MCTS for General Video Game Playing**, *Proceedings of the IEEE Conference on Computational Intelligence and Games* (2014), pp. 68-75.

2. Diego Perez, Edward Powley, Philipp Rohlfshagen, Daniel Whitehouse, Spyridon Samothrakis, Peter Cowling and Simon Lucas, **Solving the Physical Travelling Salesman Problem: Tree Search and Macro Actions**, *IEEE Transactions on Computational Intelligence and AI in Games, 6:1, pp. 31-45*, 2013.

Scientific writing:

1. Turabian KL **A Manual for Writers of Research Papers, Theses, and Dissertations.** 8th edition. Chicago (Illinois): The University of Chicago Press, 2013.

References for General Video Game Playing

Marc G Bellemare, Yavar Naddaf, Joel Veness, and Michael Bowling. The arcade learning environment: an evaluation platform for general agents. *Journal of Artificial Intelligence Research*, 47(1):253–279, 2013.

John Levine, Clare B. Congdon, Michal Bída, Marc Ebner, Graham Kendall, Simon Lucas, Risto Miikkulainen, Tom Schaul, and Tommy Thompson. General Video Game Playing. *Dagstuhl Follow-up*, 6:1–7, 2013.

Tom Schaul. A Video Game Description Language for Model-based or Interactive Learning. In *Proceedings of the IEEE Conference on Computational Intelligence in Games*, Niagara Falls, 2013. IEEE Press.