Svarog - an AI oriented language

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Chapter 1

The algorithm

The algorithm introduced in Svarog resembles minimax, with the following substantial differences:

- unlike in minimax, in Svarog there is only one agent
- the environment in Svarog is stochastic, not deterministic
- the current state of the world is not completely known to the agent

1.1 Values

The values are constants. We will denote the set of values as V.
The state of the environment is described by the values of the variables (some of them being visible to the agent are called input variables, some of them, invisible, are called hidden variables). Also the agent's decisions are defined in terms of the variables' values (for the so-called output variables).

1.2 Variables

Both the agent's input information as well as its output information is described in terms of variables' values. In Svarog there are three fundamental kinds of variables:

- input variables
- hidden variables
- output variables

1.2.1 Input variables

The input variables belong to the environment's state variables. A mapping of input variables to the set of values is called a "visible state".
We will denote the set of input variables as I. A function: $f : I \to V$ is called a visible state. The set of visible states will be denoted as VS.

1.2.2 Hidden variables

The hidden variables belong to the environment's state variables, just like the input variables. The difference is that the hidden variables are not directly observable.
We will denote the set of hidden variables as H.

A mapping of both input variables and hidden variables to the set of values is called a "state". A state is any function: $f : I \cup H \rightarrow V$. The set of all states will be denoted as S. There is a natural mapping from the set of states S to the set of visible states VS, i.e. for every state we can point to the visible state it belongs to. The visible state in question is for any state $f : I \cup H \rightarrow V$ such a function $g : I \rightarrow V$ that $\forall_{i \in I} g(i) = f(i)$.

1.2.3 Output variables

The output variables are controlled by the agent. A mapping of output variables to the set of values is called an "action". The set of all output variables will be denoted as O. An action is any function $f : O \rightarrow V$. The set of all actions will be denoted as A.

1.3 Payoff

The payoff is a certain function $p : VS \rightarrow \Re$. This function is constant and specified in a Svarog program. The objective of the algorithm is to maximize the expected value of the payoff function throughout the next n steps.

1.4 Model

The model is a collection of probability distributions. Formally it is a given constant function $m : S \times A \rightarrow P$ with P being a set of all probability distributions $f : S \rightarrow \Re$. It is therefore guaranteed $\forall_{f \in P} \sum_{s \in S} f(s) = 1$ and $\forall_{f \in P} \forall_{s \in S} f(s) \geq 0$. When referring to a model value, say $m(s_i, a)(s_t)$ we call the state s_i the "initial state" and s_t the "terminal state". The value $m(s_i, a)(s_t)$ is a probability that given the current state s_i and performing the action a the agent will encounter the terminal state s_t. We will write this value shortly $m(s_i, a, s_t)$.

1.5 Belief

For any visible state $vs \in VS$ we can define all the states belonging to it. Let's denote such states as S_{vs}. It holds: $\forall_{s \in S_{vs}} \forall_{i \in I} s(i) = vs(i)$, i.e. the state s belongs to S_{vs} if and only if it has the same value as vs for every input variable $i \in I$. Let us introduce a class of new probability distributions, namely $r : S_{vs} \rightarrow \Re$ with $\forall_{s \in S_{vs}} r(s) \geq 0$ and $\sum_{s \in S_{vs}} r(s) = 1$. Such probability distributions will be called "beliefs". Let us denote the set of all beliefs for a visible state vs with B_{vs}. At any moment the agent knows its visible state vs as well as one of the beliefs from B_{vs}.

1.6 The algorithm internals

1.6.1 get optimal action

The function goa ("get optimal action") returns for any belief from B_{vs} and natural number called "depth" $n \in N$ the action $a \in A$ such that the function $gpevfc$ ("get payoff expected value for consequences") returns maximal value for this action. In other words *goa* returns *argmax* from *gpevfc*.

1.6.2 get payoff expected value for consequences

The function *gpevfc* ("get payoff expected value for consequences") returns for any belief b from B_{vs_i}, any natural number called "depth" $n \in N$ and any action $a \in A$ a real value. The value is 0 if depth equals 0, otherwise it is

$\sum_{vs_t \in VS} cp(b, a, vs_t)(p(vs_t) + gpevfc(bfc(b, a, vs_t), n - 1, goa(bfc(b, a, vs_t), n - 1)))$

with p - payoff, bfc - belief for consequence (described later) and cp - consequence probability (described later).

Therefore *gpevfc* is a recursive function constructing a game tree for subsequent moves of our agent. For each action it checks the whole spectrum of possible consequences, for each consequence (vs_t) it calculates its probability using *cp*. In a special case when $n = 1$ this expression equals

$\sum_{vs_t \in VS} cp(b, a, vs_t)p(vs_t)$

which we recognize as the expected value of the payoff function $E(p)$. It is interesting that the beliefs passed downwards the game tree are changing - the agents "thinks": given the current belief b, an action performed a and assumed consequence vs_t I imagine my interpretation (the future belief) to be $bfc(b, a, vs_t)$ and I assume I will from then on act optimally (using *goa*). Of course b not only can but sometimes has to be different than $bfc(b, a, vs_t)$ which is a consequence of the fact that the two visible states vs_i and vs_t (called "initial visible state" and "terminal visible state") can be different.

1.6.3 belief for consequence

The function *bfc* ("belief for consequence") constructs a new belief, a new interpretation for a former belief b from B_{vs_i}, an action $a \in A$ and an observation (visible state) $vs_t \in VS$.

$bfc(b, a, vs_t)(s_t) = \sum_{s_i} b(s_i)m(s_i, a, s_t)/T$

with model m and normalization sum $T = \sum_{s_t \in S_{vs_t}} \sum_{s_i} b(s_i)m(s_i, a, s_t)$.

Note that sometimes the normalization can be impossible (when $T = 0$). Such situations are called "surprises" and normally the algorithm throws an error on them.

1.6.4 consequence probability

For any belief $b \in B_{vs_i}$, an action $a \in A$ and a visible state $vs_t \in VS$ this function constructs a real number expressing the probability that once we perform the action a in the visible state vs_i with the belief b we will end up in the visible state vs_t. The value equals:

$\sum_{s_i \in S_{vs_i}} \sum_{s_t \in S_{vs_t}} b(s_i)m(s_i, a, s_t)$

1.7 Using the algorithm

When using the algorithm the agent maintains the current belief which is subsequently adjusted to the observations using the function bfc (belief for consequence). The initial belief can be set to the prior value (for example the uniform belief). On every iteration the algorithm expects the values of the input variables, which determine the visible state.

```
do
{
std::map<variable*, value*> m;
bool eof = false;

get_input(m, eof);
if (eof)
        break;

visible_state * s = vs.get(m);

if (former_belief == NULL)
{
        set_apriori_belief(current_belief);
}
else
{
        current_belief = bfc(former_belief, former_action, s);
}
const action * a = get_optimal_action(current_belief, depth);
execute(a);
former_action = a;
former_belief = current_belief;
}
while (true);
```

The above pseudocode demonstrates the internals of the loop command in the actual implementation. Note that we use the function bfc to build the current belief depending on the former belief, the former action and the current visible state.

Chapter 2

The Svarog language

Svarog is a strict-form, AI oriented programming language. It is NOT a general purpose programming language. Its main purpose is an optimization in a game with a single agent who performs certain actions subsequently, without any opponent. The environment in the game is stochastic and the agent does not perceive the complete information about the state of the world (some state variables remain hidden).

2.1 The program structure

A program written in Svarog consists of the following parts:

- the values section
- the variables section
- the knowledge section
- any number of commands

This is an example Svarog program:

```
values {
        value false, true;
}

variables {
        input variable alpha:{false,true};
        hidden variable beta:{false,true};
        output variable gamma:{false,true};
}

knowledge {
}
```

2.1.1 Keywords

action, actions, and, assert, beliefs, case, class, cout, eol, function, generator, haskell, hidden, if, illegal, impossible, initial, input, knowledge, loop, model, not, object, objects, or, output, payoff, perkun, probability, prolog, requires, return, rules, set, state, states, terminal, test, value, values, variable, variables, visible, write, xml

2.1.2 Identifiers

A valid identifier is any word beginning with a letter (including underscore) and containing any number of letters or digits that is not a keyword.

2.1.3 Comments

A comment begins with # and ends with the end of line character.

2.1.4 String literals

A string literal is specified by the quotation marks "".

2.1.5 Float literals

A float literal is a sequence:

```
{DIGIT}+\.{DIGIT}+
```

Unary minus is not supported!

2.1.6 Integer literals

An integer literal is any number of digits:

```
{DIGIT}+
```

2.2 Values section

The values section beginns with the keyword "values" followed by { and ends with }. It may contain any number of the statements:

```
value identifier1 ,identifier2 ,...;
```

The identifiers must be valid identifiers (not keywords) and must not occur more than once each of them.

Example of a values section:

```
values {
        value false, true;
        value none;
}
```

2.3 Variables section

The variables section begins with the keyword "variables" followed by { and ends with }. It may contain any number of variable declarations. There are three kinds of variable declarations:

- input variable declaration
- hidden variable declaration
- output variable declaration

2.3.1 Input variable declaration

The input variable declaration begins with "input variable" followed by any number of variable inner declarations separated by commas, terminated by semicolon. A variable inner declaration is a variable name (an identifier) followed by colon, followed by a list of variable values enclosed in {}. For example:

```
input variable a:{false,true},b:{false,true};
```

The above input variable declaration contains declarations of two input variables, "a" and "b", each of them having the values "false" or "true".

2.3.2 Hidden variable declaration

The hidden variable declaration begins with "hidden variable" followed by any number of variable inner declarations separated by commas, terminated by semicolon.

```
hidden variable c:{false,true},d:{false,true};
```

The above hidden variable declaration contains declarations of two hidden variables, "c" and "d".

2.3.3 Output variable declaration

The output variable declaration begins with "output variable" followed by any number of variable inner declarations separated by commas, terminated by semicolon.

```
output variable e:{false,true},f:{false,true};
```

2.4 Knowledge section

The knowledge section in a Svarog program contains any number of:

- functions
- "impossible" clauses
- "payoff" clauses
- "action" clauses

2.4.1 Function

A function begins with the keyword "function" followed by an identifier (the function name), followed by a list of parameters enclosed in (), followed by the function body enclosed in curly brackets {}. The parameters in the list of parameters are separated with commas. Each parameter is an identifier preceded with the keyword "variable" or the keyword "value".

An example of a function:

```
function is_initially_in(variable where_is_x, value town)
{
        if (initial value where_is_x == town)
        {
                return true;
        }
        return false;
}
```

The function body consists of the commands "if" and commands "return". For each variable (either a parameter or directly accessed input or hidden variable) it is possible to access either its initial value or terminal value. The conditions in the "if" commands can use "and" and "or" operators, as well as "not" and round brackets ().

2.4.2 "Impossible" clause

Certain states are impossible. They are marked as such with the "impossible" clause. They will be omitted by the algorithm during the calculations.

An example of such clause is:

```
impossible "dorban and pregor are in the same town yet dorban cannot see pregor" {
        requires initial value where_is_dorban == initial value where_is_pregor;
        requires initial value can_dorban_see_pregor == false;
}
```

2.4.3 "Payoff" clause

Example:

```
payoff "payoff for winning a fight":100.0 {
        requires initial value has_dorban_won_a_fight == true;
}
```

The payoff clause specifies the payoff function value for a certain state. In the above example the value equals 100.0 "points" if the initial value of the variable has_dorban_won_a_fight equals true. The payoff clause body may contain any number of the "requires" clause.

"Requires" clause

The "requires" clause consists of the "requires" keyword followed by a logical expression (possibly using "and", "or" and "not") referring to the input variables' initial values. It is allowed to use here also the functions (defined elsewhere within the knowledge section).

In the payoff clause body one must not use the hidden variables. Payoff is defined in terms of the input variables only.

2.4.4 "Action" clause

An action clause consists of the keyword "action" followed by an action query, followed by colon, followed by the clause body enclosed in the curly brackets {}. Example:

```
action {optimal_action=>ask_pregor_to_follow_dorban}:{
# here comes the action clause body
}
```

The action clause body contains any number of the "case" clauses appropriate for this action.

"Case" clause

A "case" clause consists of the "case" keyword followed by a string literal describing the case (used only for debugging purposes) and a case clause body enclosed in the curly brackets {}. In the case clause body the following constructs are allowed (any number):

- requires clause
- illegal clause
- probability clause

"Requires" clause

The "requires" clause consists of the "requires" keyword followed by a logical expression (possibly using "and", "or" and "not") referring to the input variables' initial values. It is allowed to use here also the functions (defined elsewhere within the knowledge section).

"Illegal" clause

The "illegal" clause consists of the keyword "illegal" followed by a semicolon. This clause specifies that using the action is illegal in this situation. Example:

```
case "dorban does not see pregor" {
requires initial value can_dorban_see_pregor==false;
illegal;
}
```

"Probability" clause

A "probability" clause consists of the "probability" keyword followed by a string literal, followed by colon and float literal, followed by the probability clause body. The float literal passed here is the probability value (it must not be greater than 1.0).

```
probability "dorban with pregor succesfully attack the vampire" : 0.75{
        requires terminal value has_dorban_won_a_fight==true;
        requires initial value where_is_vampire == terminal value where_is_vampire;
        requires initial value where_is_dorban == terminal value where_is_dorban;
        requires initial value where_is_pregor == terminal value where_is_pregor;
        requires terminal value can_dorban_see_vampire == true;
        requires terminal value can_dorban_see_pregor ==true;
        requires terminal value is_pregor_following_dorban==true;
}
```

The ”requires” clauses in the ”probability” clause body may refer both to the input and hidden variables, both initial and terminal values.

If multiple ”probability” clauses are used within a single ”case” clause their probabilities should sum up to 1.0.

2.5 Commands

After the values section, variables section and knowledge section any number of commands follow.

2.5.1 Loop

The command ”loop” asks svarog to enter the interactive mode. In this mode the user is first asked to type the input variables’ values in the given order (separated by space characters) and then svarog prints out its belief and the chosen optimal action.

The command ”loop” has the following syntax: The keyword ”loop” followed by (, followed by integer literal, followed by), followed by semicolon. The integer literal is the depth of the game tree passed to the ”get_optimal_action” function.

Example:

```
loop(5);
```

2.5.2 Printing out the visible states

It is possible to print out the visible states to the standard output with the following command:

```
cout << visible states << eol;
```

2.5.3 Printing out the states

It is possible to print out the states to the standard output with the following command:

```
cout << states << eol;
```

2.5.4 Printing out the knowledge

It is possible to print out the knowledge to the standard output with the following command:

```
cout << knowledge << eol;
```

2.5.5 Test

There is a command ”test” to verify whether the model specified by the knowledge is valid. The results will be printed out to the standard output. The syntax is:

```
test();
```

There is also a specialized version of the command with a query as a parameter.

Chapter 3

The svarog tool

The svarog tool is an interpreter of the Svarog language. It is a program (written in C/C++ with Bison and Flex) that obtains as input a file name. This file should contain a valid Svarog specification.

3.1 Building the svarog tool

Download and unpack the svarog tarball from the website www.perkun.org. Enter the directory svarog-0.0.1 (or any newer, if available). Execute the command:

```
./configure
```

3.1.1 Prerequisites

The following tools are necessary to build svarog from source:

- flex - a tool to generate scanners
- bison - a tool to generate parsers
- readline - a library

3.1.2 Compiling the svarog

Once configured, execute the command:

```
make
```

If no errors occur then execute:

```
sudo make install
```

3.2 Interactive mode

If a svarog specification contains the command loop then after execution it will enter the interactive mode.

Chapter 4

The libsvarog library

The libsvarog library is built and installed automatically when the svarog tool is built and installed. In order to use the library in your C++ project add the following line to your configure.ac file:

```
PKG_CHECK_MODULES([SVAROG], [libsvarog >= 0.0.1])
```

Depending on your system you might need to set the environment variable PKG_CONFIG_PATH:

```
export PKG_CONFIG_PATH=/usr/local/lib/pkgconfig
```

4.1 Using the libsvarog library in your C++ projects

In your Makefile.am located near the source code of your project you might need to specify:

```
AM_CXXFLAGS = @CXXFLAGS@ @SVAROG_CFLAGS@
```

You may also need to add the @SVAROG_LIBS@ to your x_LDADD variable provided the program you build is named x.

4.1.1 Including the svarog header file

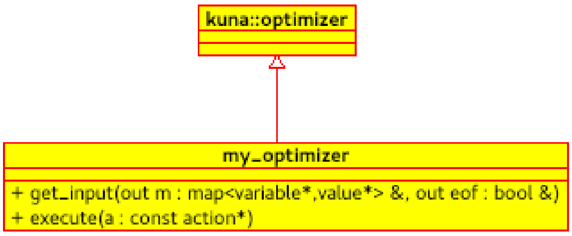
In you header file (for example x.h) you might want to include the svarog header file:

```
#include <svarog.h>
```

4.1.2 Inheriting the svarog::optimizer

You should define a new C++ class inherited from the svarog::optimizer class, for example:

```
class my_optimizer: public svarog::optimizer
{
public:
virtual void get_input(std::map<svarog::variable*, svarog::value*> & m, bool & eof);
virtual void execute(const svarog::action * a);
};
```



As you can see above at least two functions should be redefined: get_input and execute.

4.1.3 Surprise handling

You might also want to redefine the virtual function:

```
virtual void on_surprise(const svarog::belief & b1, const svarog::action & a,
        const svarog::visible_state & vs, svarog::belief & target);
```

The original implementation of this function throws an error. It happens when the belief (interpretation of the visible state vs) cannot be constructed, because the probability of the consequence vs was 0.0. You may want to replace this handling by a more gentle one, for example:

```
void my_optimizer::on_surprise(const svarog::belief & b1, const svarog::action & a
const svarog::visible_state & vs, svarog::belief & target)
{
        target.make_uniform();
}
```

You might also try to use the former belief b1 to construct a valid target belief.

4.2 Pipes and forks

It is recommended to embed svarog in a multiprocess application with the pipes created for both direction communication and the svarog interpreter (the class inherited from svarog::optimizer) running in a child process forked from the main process. The function my_optimizer::get_input should either set the eof flag to true or populate the map m with the appropriate values corresponding with the input variable values.

When instantiated, the new optimizer should call the function parse(const char * program) and if it succeeds (returns zero) then it should call the function run().

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