Using of Synchronous Distributed Automata paradigm in software development

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Ver.0.03 at 09-Dec-2010

Revision History		
Revision 0.01	10-Mar-2010	Yuri Borisov
Initial version		
Revision 0.02	21-May-2010	Anna Lemekhova
Added the section called “Example: SR flip-flop”		
Revision 0.03	09-Dec-2010	Anna Lemekhova
Migrated from Dynamic System approach to automata.		

Table of Contents

Glossary

DTDS

Discrete Time Dynamic System

See Also Discrete Time Dynamic System.

Discrete Time Dynamic System

The some phenomenom "black box" model based on input - internal states - output. Ref [WIKI_DS] for base info.

See Also DTDS.

DDS

Discrete Dynamic System

DSO-MBP

Dynamic System Oriented Model Based Programming

See Also Simulink.

DSA

Distributed State Automation.

FSA

Finite State automata

FAP

Finite Automata Paradigm framework. The framework for SW development with using of FSAparadigm.

Ref [FAP_GIT] for source code repository

Simulink

The modelling tool of Discrete Dynamic Systems

References

[SCRAFT_RU_AUTO] http://workbort.ru/auto.shtml.htm. *Using of finite automata in SW disign [RU]*.

[SC_LUBCH_ABP_1] http://www.softcraft.ru/design/katech.shtml. *Любченко В.С., Конечно-автоматная технология программирования*.

[WIKI_DS] http://en.wikipedia.org/wiki/Dynamical_system. *Dynamical system. From Wikipedia, the free encyclopedia*.

[WIKI_DDS] http://en.wikipedia.org/wiki/Discrete-time_dynamical_system. *Discrete time Dynamical system. From Wikipedia, the free encyclopedia*.

[DS_ORG] http://www.dynamical-systems.org/. *dynamical-systems.org*.

[LYUBCH_RS_TRIG] http://workbort.ru/auto/ka/rsm/rsm01.shtml.htm. *Любченко В.С. Искусство программирования ... RS-триггера?!* .

[WIKI_RS_TRIG] http://en.wikipedia.org/wiki/Flip-flop_(electronics). *Flip-flop (electronics). From Wikipedia, the free encyclopedia*.

[WIKI_FSA] http://en.wikipedia.org/wiki/Finite_state_machine. *Finite-state machine. From Wikipedia, the free encyclopedia*.

[WIKI_AUT_THEORY] http://en.wikipedia.org/wiki/Automata_theory. *Automata theory. From Wikipedia, the free encyclopedia*.

[FAP_GIT] http://gitorious.org/fap. *FAP project git repository*.

[FAP_DEMO_SNAILS] http://gitorious.org/fap/fap-snails. *FAP demo application "Snails" git repository*.

Introduction

Finite state automata (FSA) is one of the paradigms that can be used for SW development.

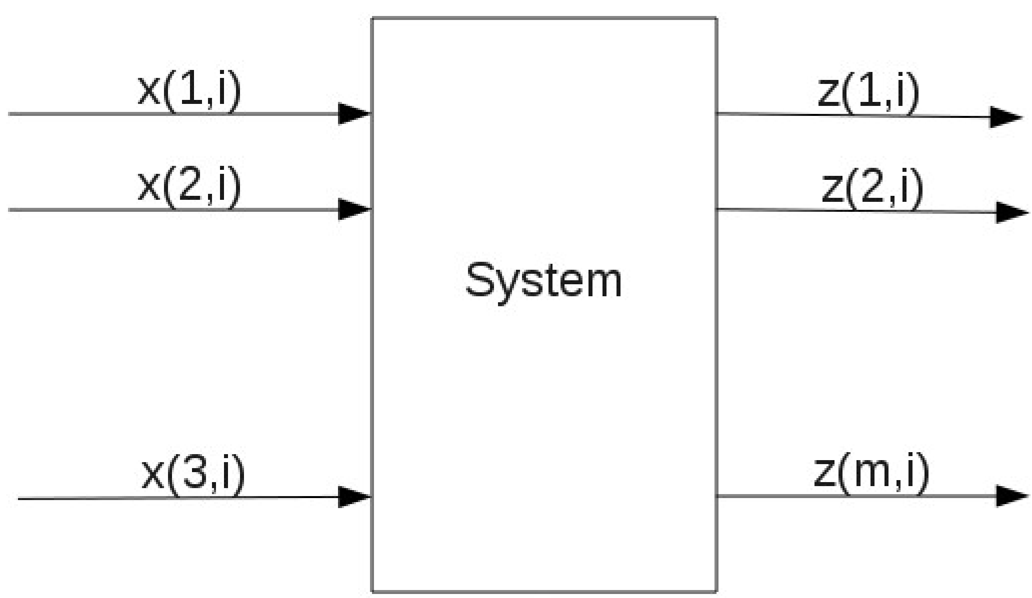
The key specifics of this paradigm are:

- Native parallelism - the model consists of interconnected automata
- Events based approach - automate is updated only on event received

The paradigm has tough relation to concept of Discrete Time Dynamic System.

Discrete Dynamic System introduction

Let's consider the concept of Discrete Time Dynamic System first. The system can be considered as a "black box" with *n* input (x) and *m* output (z) variables, which value can be changed in the ticks of discrete time *i*:



Also there are internal variables (states) *s(k,i)* that determine system behaviour. Discrete time *i* is unite for the system and "synchronyze" the sets of inputs, outputs and states. So this system is called "synchronous"

One more resriction is that the set of inputs, states, and output values (alphabet) is finite.

Refer to [WIKI_DDS] section "General definition" for the formal definition.

A discrete dynamical system (DDS) can be represented by the tuple *(T, S, F, G, X, Z, s0)* where,

T is a discrete time

S is a set called state space

X is the set of inputs values

Z is the set of output values

s0 is an initial state of the system

G is a function that called "output function"

F is a function that called "evolution function"

$F : U \subset X \times S \longrightarrow S$

Another representation form of DDS is:

s(i) = F(i, s(i-1), x(i))   (4)

z(i) = G(i, s(i), x(i))   (5)

In many cases the status *s* of system can be represented by the vector that consists of *n* elements

s = [s0, s1, ..., sn]

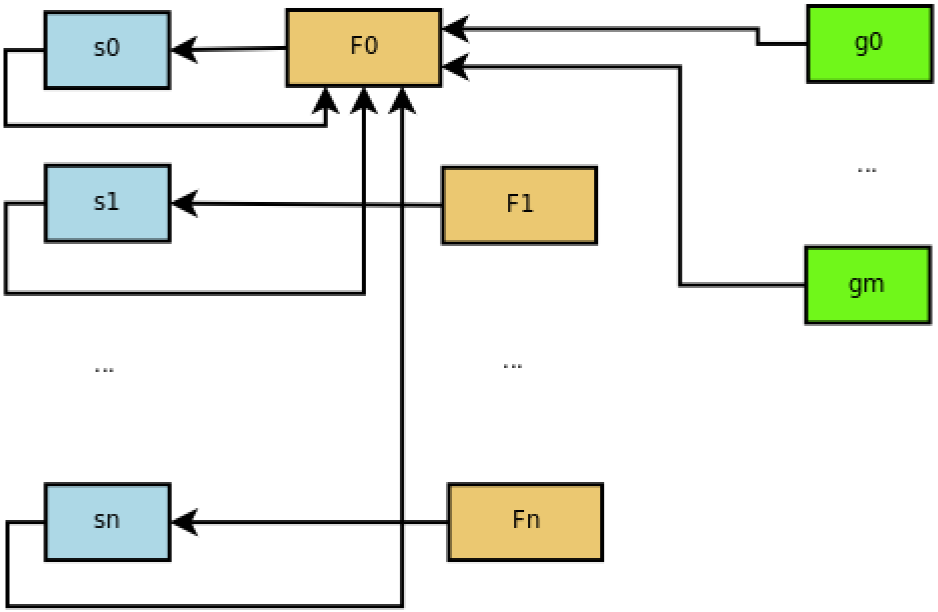
The input *s* is a vector that consists of *m* elements

x = [x0, x1, ..., xn]

The element of status will be called "state variable" or "state" below while for the vector *s* will be term "system state" used

This can be represented by the scheme below:

Figure 1. DDS scheme



Accorfing to the scheme the system structure includes state variables, transition function for each state variable, and the inputs.

A short view to finite automata

Ref [WIKI_AUT_THEORY] for WiKi article with math base of FSA

Now we can define FSA as a synchronous system that is characterised by six-tuple:

G = (X, Y, S, f, g, s0)

where

- X - input alphabet
- Z - output alphabet
- S - set of states
- f - transion function
- g - output function
- s0 - initial state

and

s(i) = f(x(i), s(i-1)   (1
)

z(i) = g(x(i), s(i))   (2)

It can be noted that the term "state" is used differently for FSA and DDS: for FSA it often means the element of states set, i.e state value, while for DDS it ofter means "state variable"

SW design approach using DDS and FSA

Consider SW system design based on DDS representation the section called “Discrete Dynamic System introduction”, the section called “Discrete Dynamic System introduction”, and Figure 1, “DDS scheme”

Basing on representation of whole system state *s*as a vector of system state elements variables *sk*, the equation the section called “Discrete Dynamic System introduction” can be written via set of equations for each variable:

sk(i) = Fk(i, sk(i-1), x(i))   (6)

where

- Fk - transition function for state variable sk

So the whole system can be factored into the set of particular state variables with assosiated transition functions

Lets also assume that system can be created as a set of subsystems, that can interact one to another, i.e be connected.

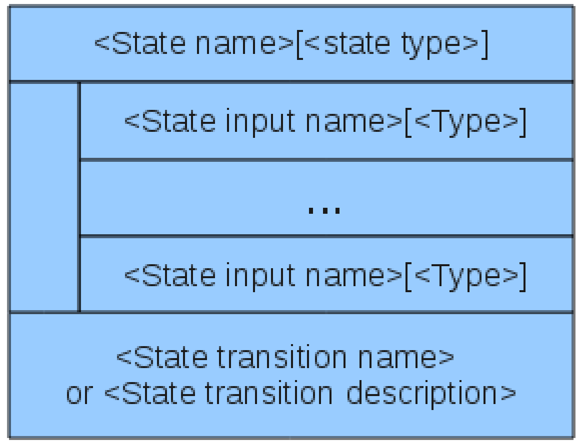
As can be seen from the Figure 1, “DDS scheme” each state variables is finite automata where set of state is the set of possible values of state variable, and input events are the state variable inputs values.

Then the whole scheme can be created with two kinds of elements - state variable and object (sybsystem):

- State variable includes the variable, transition function, and set of inputs
- Object includes one or more state variables, one or more sub-objects and connections between them

Let's illustrate the approach using the examples of systems implementation. To simplify analysis of the examples we can use graphic notation for the object and state.

Graphic notation for the state can be as:



State notation includes:

- State name - uniquely identifies the state within an object
- State type - uniquely identifies the type of state. Actually it identifies the type of data, for instance Boolean, etc.
- State input name- uniquely identifies input, the name used within transtion function. Also the type of input are specified.
- Transion function - is specified via identificator and/or the description of function

The scheme of system then consists of states and "links" that connect state to other state depending on it.

In order to simplify object as a syblystem we can separate all the states of the object into three groups:

- Regular states - or internal states, hidden for access from other sybsystem
- Input states - can be accessed from out of object and can be set as dependent on other object output states
- Outpus states - can be accesses form out of object and can be used as states from which connected object's input states are dependent on

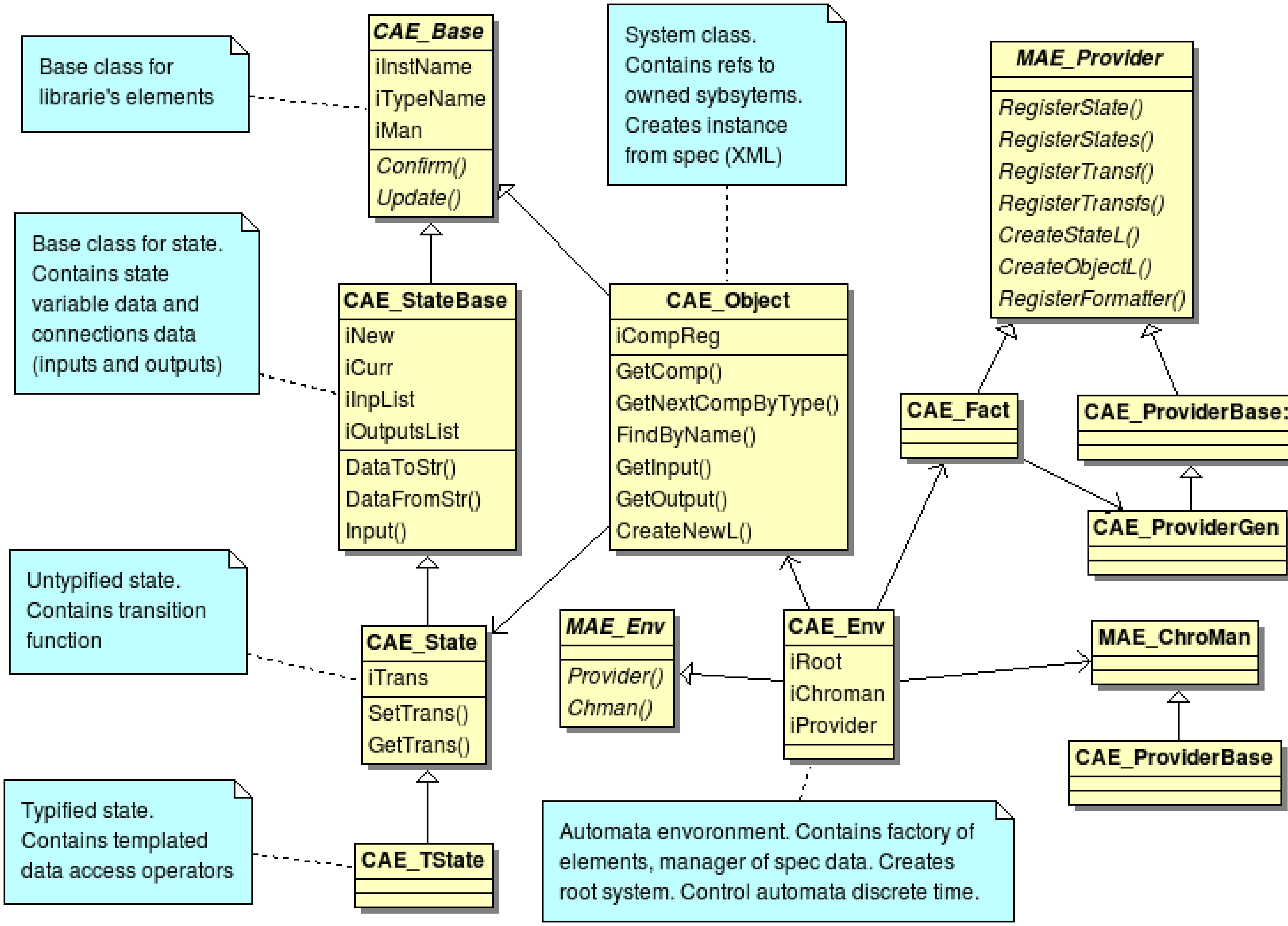
We can also use some different type of notation based on UML notation because of convenience of using UML editor

Framework for finite automation paradigm

There was the framework FAP created for the purpose of trying and analysing FSA paradigm in SW development. Ref [FAP_GIT] for source code repository

Below is the structure and APIs of the FAP libraries outlined:

Figure 2.



The structure of system is described by system spec - XML document, that specified the sybsystem and connections between them.

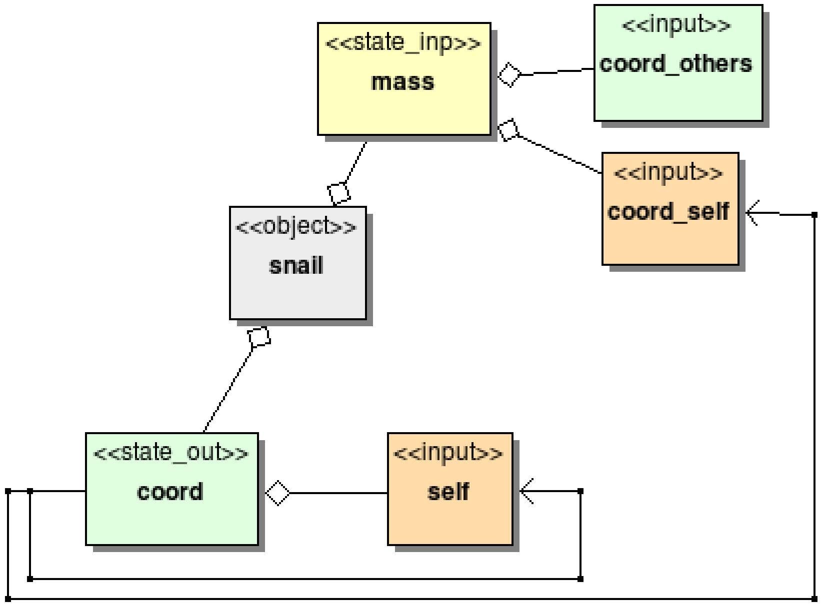
FAP libraries were used for develop examples given in the current article.

Examle: Snails

Let's illustrate the idea of FSA using with the example - simple application where the race of three snails simulated. The snail in this action does two thinks: moving and eating. The leader in the race gets more food so increases his weigth. But the more weigth is snail, the less velocity he moves.

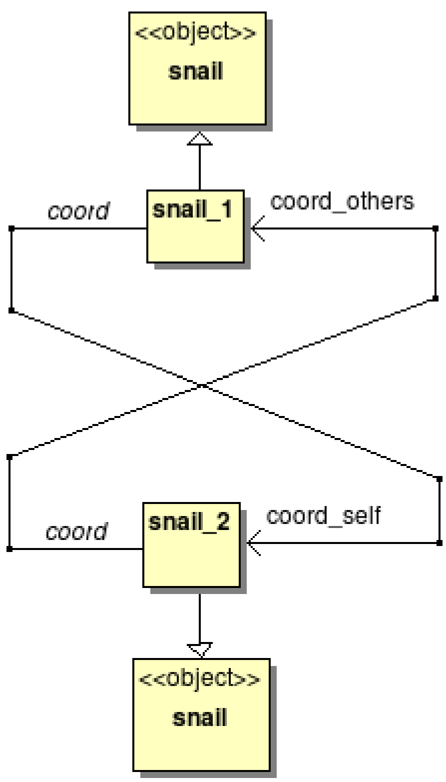
Let's simulate state by the subsystem, containing state variables for the weight and coordinate on race-track.

Figure 3.



The whole system includes three snails and connection between them. The diagram below shows the system structure for two snails.

Figure 4.



Let's create FAP spec for the system:

Example 1. Snails spec

```
            <caeenv>
                <object type="test" id="main_test">

                    <!-- *************************** SNAIL BASE
*******************************  -->
                    <object type="none" id="snail" quiet="yes">
                        <logspec  event="cre"> <logdata id="new"/> </logspec>

                        <state type="StUint32" id="mass" access="Inp"
transf="trans_mass" init="2">
                            <logspec event="upd"> <logdata id="new"/> </logspec>
                            <inp id="coord_self"/> <inp id="coord_others.*"/> </state>

                        <state type="StUint32" id="coord" len="4" access="Out"
transf="trans_coord" init="0">
                            <logspec event="upd"> <logdata id="cur"/> <logdata
id="new"/> </logspec>
                            <inp id="self"/> <inp id="mass"/> </state>

                        <conn state="mass"> <dep inp="coord_self" conn="coord"/>
</conn>
                        <conn state="coord"> <dep inp="self" conn="coord"/> <dep
inp="mass" conn="mass"/> </conn>
                    </object> <!-- snail -->

                    <!-- *************************** SNAIL INSTANCES
*******************************  -->
                    <object type="snail" id="snail_1" > <state mut="Change" id="mass"
init="7"/></object>
                    <object type="snail" id="snail_2" > <state mut="Change" id="mass"
init="3"/></object>
                    <object type="snail" id="snail_3" > <state mut="Change" id="mass"
init="16"/></object>


                    <!-- *************************** CONNECTIONS
*******************************  -->
                    <conn state="snail_1.mass"> <dep inp="coord_others.1"
conn="snail_2.coord"/> <dep inp="coord_others.2" conn="snail_3.coord"/> </conn>
                    <conn state="snail_2.mass"> <dep inp="coord_others.1"
conn="snail_1.coord"/> <dep inp="coord_others.2" conn="snail_3.coord"/> </conn>
                    <conn state="snail_3.mass"> <dep inp="coord_others.1"
conn="snail_1.coord"/> <dep inp="coord_others.2" conn="snail_2.coord"/> </conn>

                </object> <!-- test -->
            </caeenv>
```

We also need to implement transition functions for snail coordinate and mass:

Example 2.

```
void update_mass(CAE_Object* /*aObject*/, CAE_State* aState)
{
```

```
    CAE_TState<TUint32>& self = (CAE_TState<TUint32>&) *aState;
    const TUint32& coord_s = self.Inp("coord_self");

    TInt feed = KMaxFeed;
    for (TInt i = 1; self.Input("coord_others", i) != NULL; i++) {
        const TUint32& coord_o = self.Inp("coord_others", i);
        if (coord_o > coord_s && feed > 0)
            feed--;
    }
    TUint32 newmass = ~self + feed - 1;
    self = (newmass > KMass_Max) ? KMass_Max: ((newmass < KMass_Min) ? KMass_Min :
newmass);
}

void update_coord(CAE_Object* /*aObject*/, CAE_State* aState)
{
    CAE_TState<TUint32>& self = (CAE_TState<TUint32>&) *aState;
    const TUint32& mass_s = self.Inp("mass");
    self = ~self + KMass_Max/mass_s;
}
```

And finally we need to create automata environment, and run the automata time

```
        iEnv = CAE_Env::NewL(NULL, tinfos, KSpecFileName, 1, NULL, KLogFileName);
```

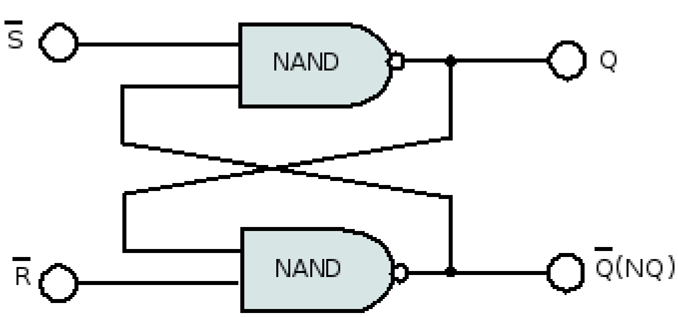
The source code of application can be accessed on repository [FAP_DEMO_SNAILS]

Example: SR flip-flop

Lets simulate work of SR flip-flop [WIKI_RS_TRIG] using DDS.

It is possible to construct SR flip-flop using either two NOR or two NAND gate.

The SR NAND gate latch:



The boolean formula:
Q = !(!S & NQ)

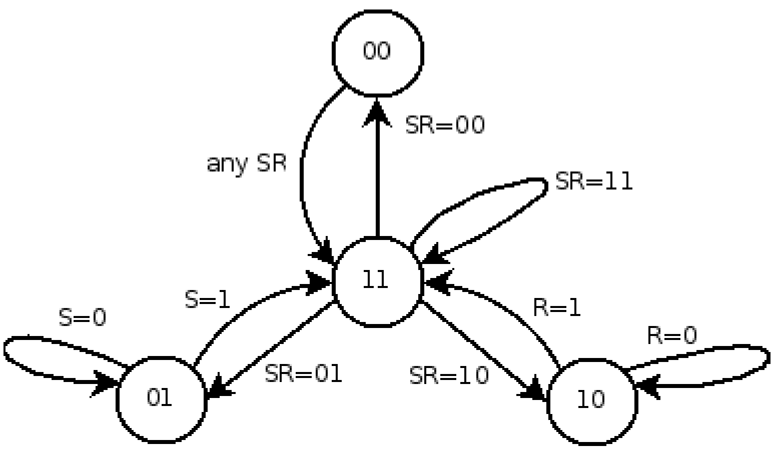
NQ = !(!R & Q)

R (reset) and S (set) are known as external inputs. Q is known as external output and NQ is its inverse output. There is feedback from each output to one of gate inputs. The problematic of SR flip-flop programming is related to these feedback, as additional synchronization actions to perform calculation are required.

When having initial input values at t=t0 (Q(t0)=Q0, NQ(t0)=NQ0, S(t0)=S0, R(t0)=R0), the next step results at t=t1 can be obtained after applying boolean NAND operation twice:

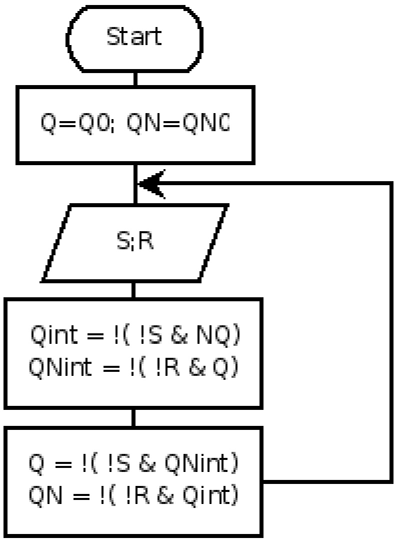
Step 1:	Qint = !(!S0 & NQ0)	Step 2:	Q1 = !(!S0 & NQint)
	NQint = !(!R0 & Q0)		NQ1 = !(!R0 & Qint)

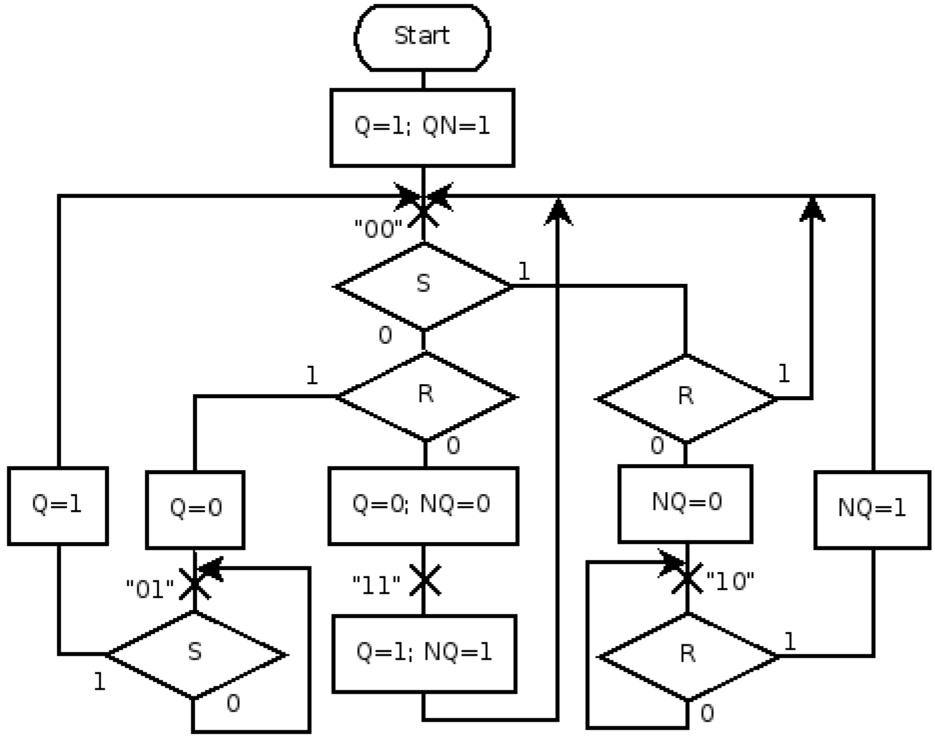
Generally there are four possible combinations of (Q, NQ). But from trigger point of view only (0,1) and (1,0) are correct. They are known as stable states (state (Q1, NQ1)). (1,1) is an intermediate (Qint, NQint) unstable state. All transitions between stable states are performed through intermediate state. This is push-pull (in-out) trigger scheme. The diagram below [LYUBCH_RS_TRIG] describes the process and conditions of states switching:



In [LYUBCH_RS_TRIG] the pros and cons of several SR flip-flop models are described, among them there are sequential flowchart model, parallel synchronous FSA model (our FAPWS is exactly such case) and asynchronous Petri net model. It will take time and efforts for an uninformed reader to investigate all these schemes and graphs. Petri net is far-fetched here, of course it is more suitable for asynchronous systems. So it makes no sense to evaluate it.

When having no additional tools (except C or C++) I would choose sequential variant with explicit intermediate state (SIS) or "if" sequential option [LYUBCH_RS_TRIG]:





Digression. Some simplification can be made:
Q1 = !(!S0 & NQint) = !(!S0 & (!(!R0 & Q0))) = S0 | !R0 & Q0

In this case we don't need NQ at all, Q is defined by S, R and previous Q. But this is another model.

But having such tool as FAPWS library, I would prefer it. The reasons are the following:

- operation decrease: if in intermediate state S or/and R is changed, they will be used in generation. On one hand we miss stable state, but on the other hand we reduce number of operations. Let's illustrate this with input sequences:
  (Q0,NQ0)=(1,0) SR_1= 01, 01, 01, 01, 01, 01, 01, 01, 10

  FAPWS: (1,0) 01 -> (1,1) 01 -> (0,1) 01 -> (0,1) 10 -> (1,1) 10 -> (1,0) 10

  SIS: [(1,0) 01 -> (1,1) 01 -> (0,1) 01] -> [(0,1) 01 -> (0,1) 01] 7 times -> [(0,1) 10 -> (1,1) 10 -> (1,0) 10]

  and:
  (Q0,NQ0)=(1,0) SR_2 = 01, 10

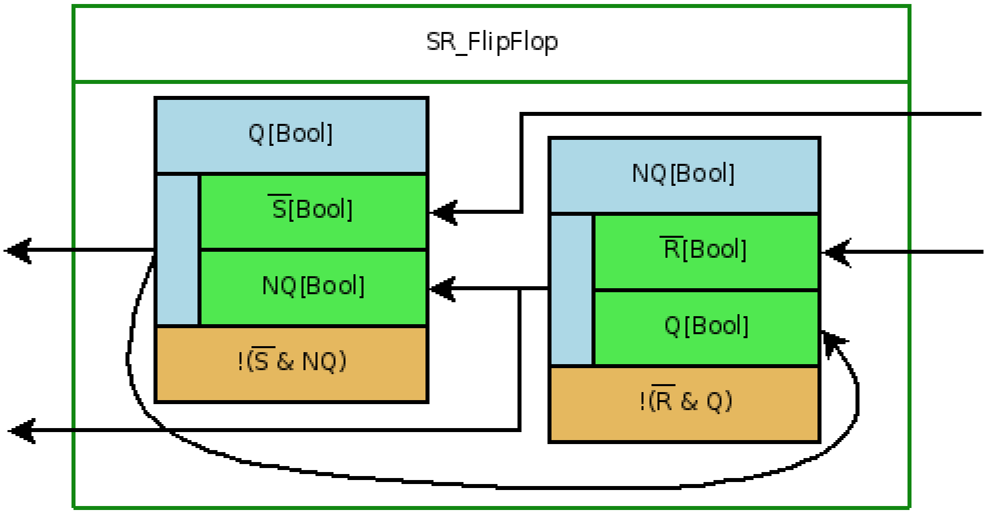
  FAPWS: (1,0) 01 -> (1,1) 10 -> (1,0) 10 - state is missed here

  SIS: [(1,0) 01 -> (1,1) 01 -> (0,1) 01] -> [(0,1) 10 -> (1,1) 10 -> (1,0) 10]

  State skipping can be easily avoided by 2 step operations after each S or/and R setting.
- code decrease is achieved by:
  a. xml generation. All you need is xml spec and two transition functions registered in environment object
  b. no checks for data change is required

- clear notation, support states of standard encapsulated data, states of user defined data can be added

  The SR DDS notation:



The conclusion is that DDS and its realization FAPWS library can be useful (and simplify our life) even in such a trivial example as SR flip-flop.