Tutorial
Agent-based Programming using FLAME

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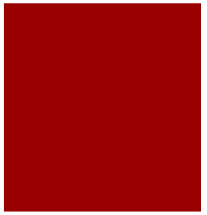
Overview for today

- Schedule and organization
- What is agent-based modelling?
- Introduction to C programming language
- Introduction to FLAME Framework
- Simple exercises

Schedule and organization



14.00 - 15.00: C - theory

15.00 - 15.45: C – exercises

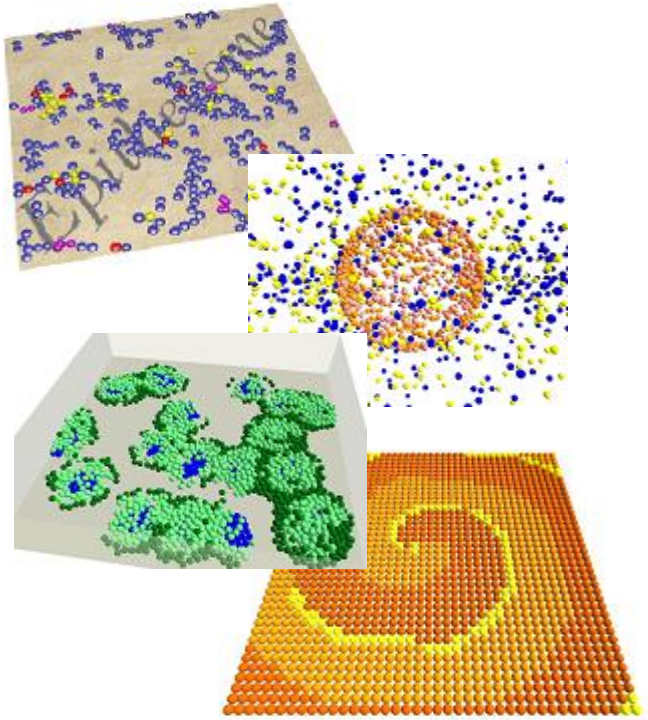
15.45 - 16.00: Break

16.00 - 17.00: FLAME - theory

17.00 - 18.00: FLAME - exercises

What is FLAME?

- FLAME stands for: Flexible Large-scale Agent Modelling Environment
- An easy agent-based modelling environment
- Based on a formal model of computation: X-machines
- Used in a European research project: EURACE on Agent-based Macroeconomics
- Other projects range from biology to crowd simulation: cells to organisms
- Uses the C language as a basis



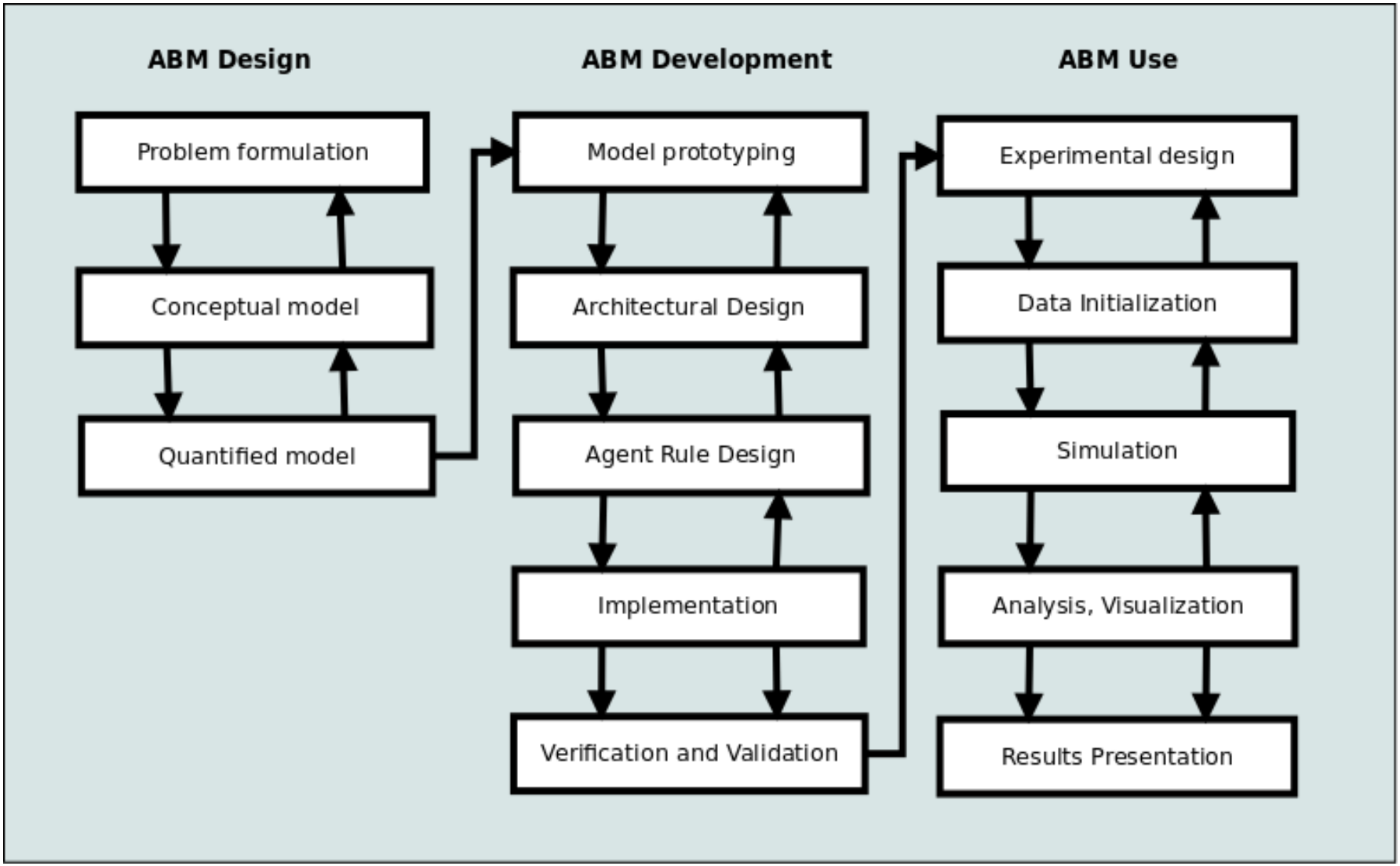
What are agents?

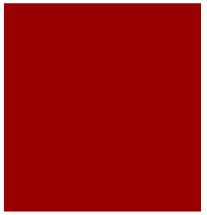
- Agents are software objects that have states and rules to change states (transition functions).
- Agents are:
  - Identifiable (distinct from other agents)
  - Autonomous (make decisions)
  - Purpose-driven (have goals)
  - Adaptive (change behavior)
  - Interactive (communicate)
  - Social (part of agent society)

What is an Agent-Based Model?

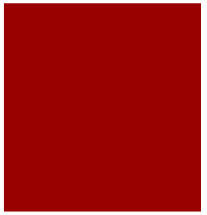
- Agent-Based Models (ABMs) are software systems consisting of agents.
- A **generative** (bottom-up) approach
- Benefits:
  - Involves natural description of a system
  - Flexible and extensible
  - Can reproduce emergent phenomena

Model development cycle





FLAME Tutorial 1: Understanding FLAME



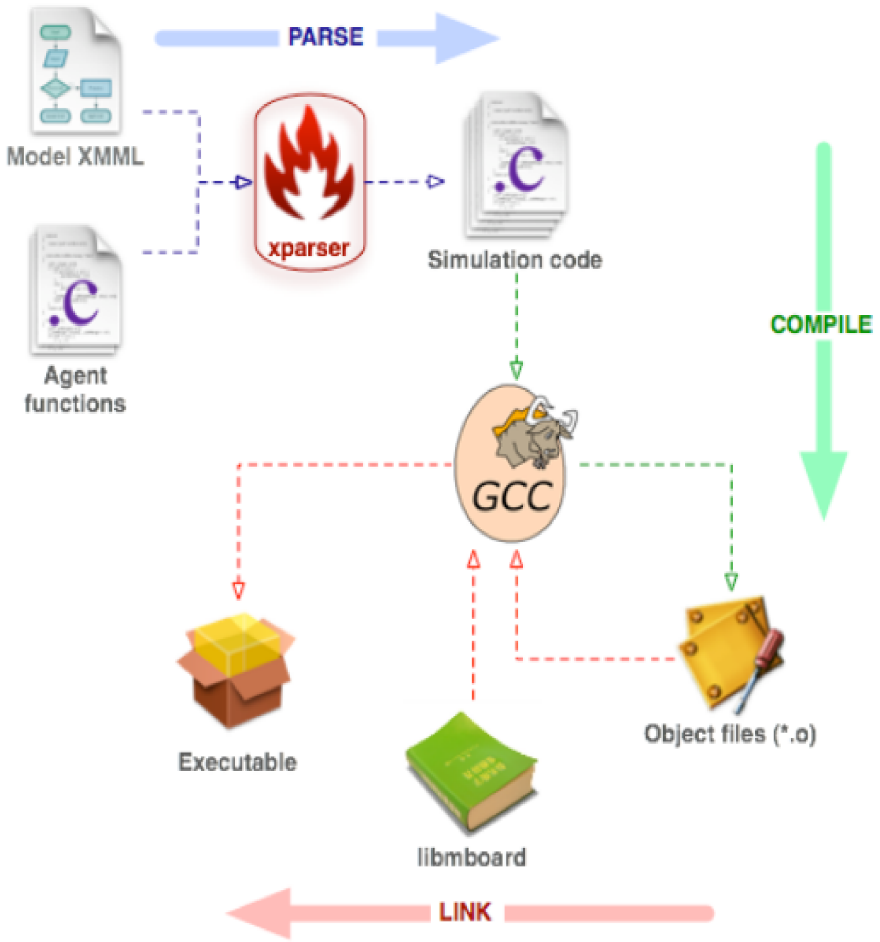
FLAME consists of two components

- **Xparser**
  - Tool that generates application based on defined model
  - Can generate both serial and parallel simulations
  - Generates state diagrams
  - Generates Makefile (automate compilation)

- **Message Board Library**
  - Supporting library that handles data management
  - Enables agents to interact efficiently with environment
  - Allows the simulation to be run in parallel

Using FLAME

1. Describe the model
2. Code behaviour of each agent
3. Generate simulation code using the Xparser
4. Build the executable using “make”
   - Compiles code to object files
   - Links with necessary libraries, include Message Board library
5. Run the executable on an initial population
6. Observe results



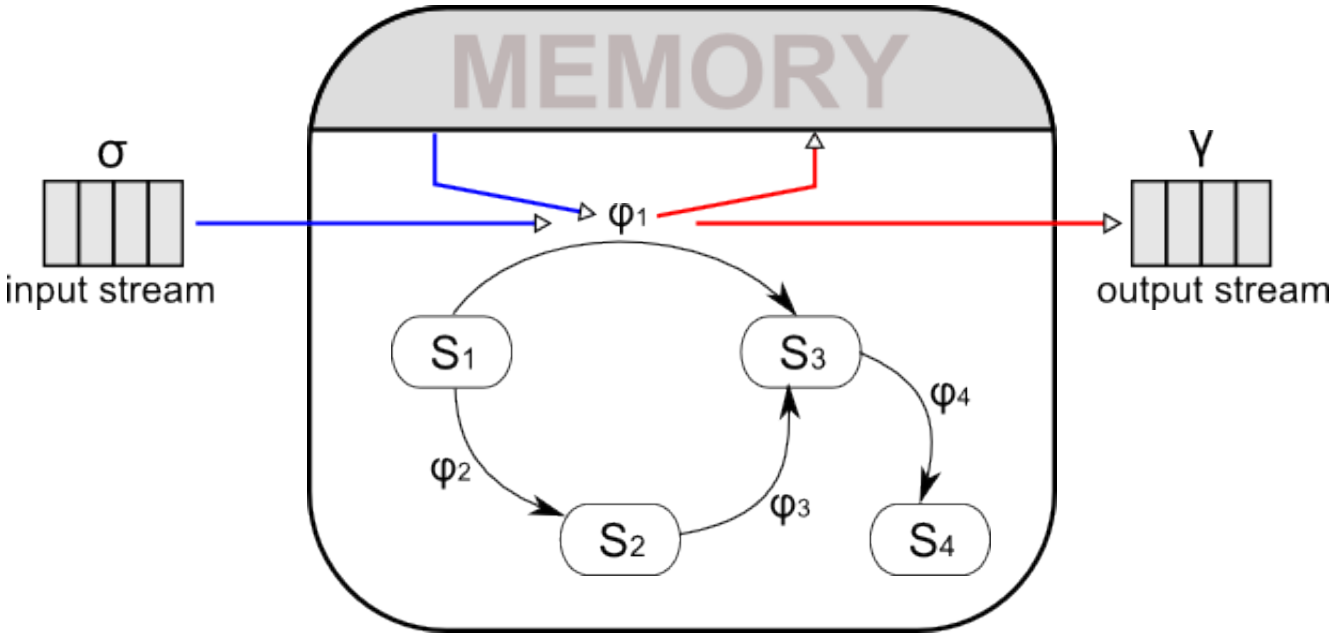
Creating a model

What do you need to define?

- **Agents**
  - Memory
  - Behaviour
  - States
- **Messages** (information flow between agents)
- **Optional extras**
  - Environment constants (model parameters)
  - Custom data types
  - Custom time units
  - Function activation conditions

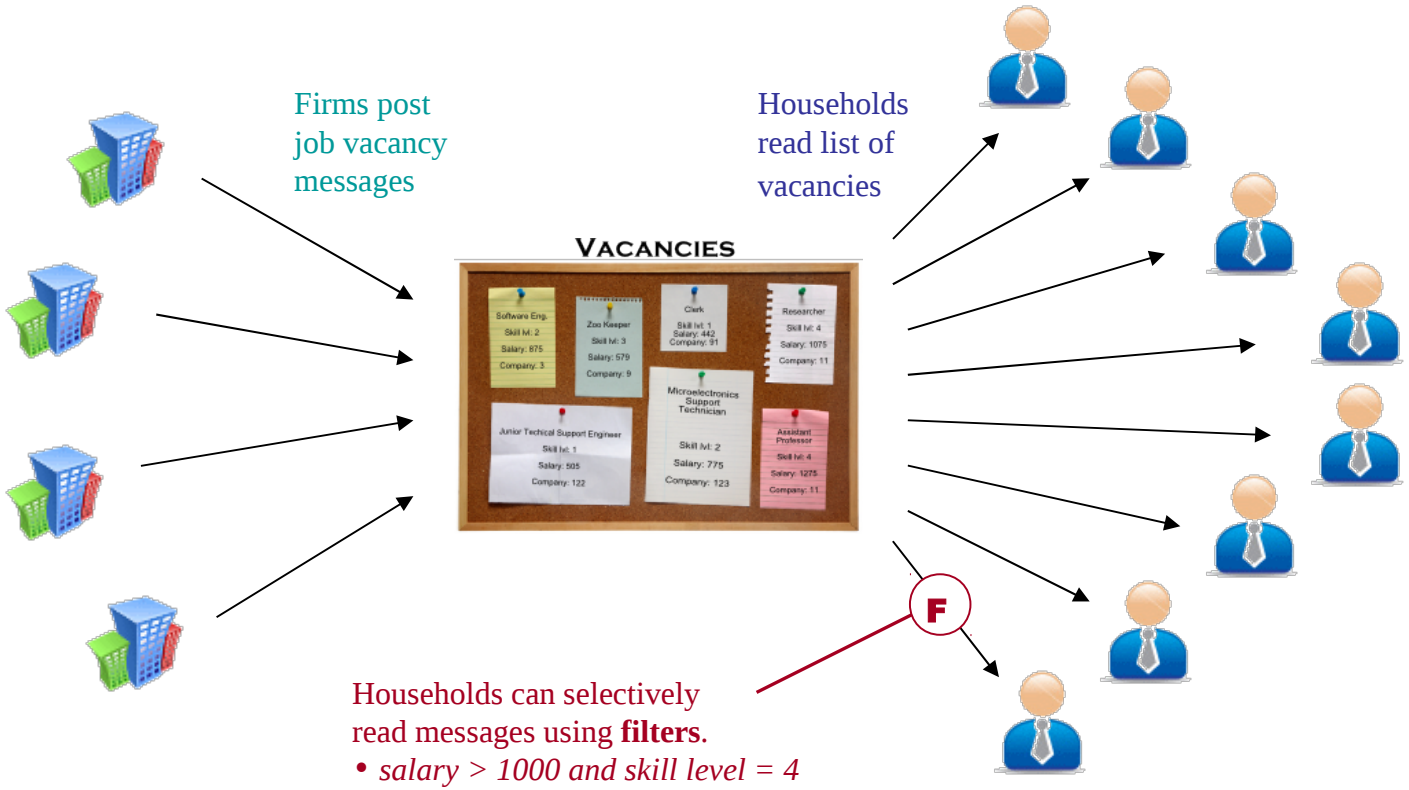
Agents

Agents defined based on formal concept of Communicating Stream X-Machines (CXSM)



Message Boards

Agents communicate through message board**s**.



For **efficiency** and **consistency**, there are some constraints:

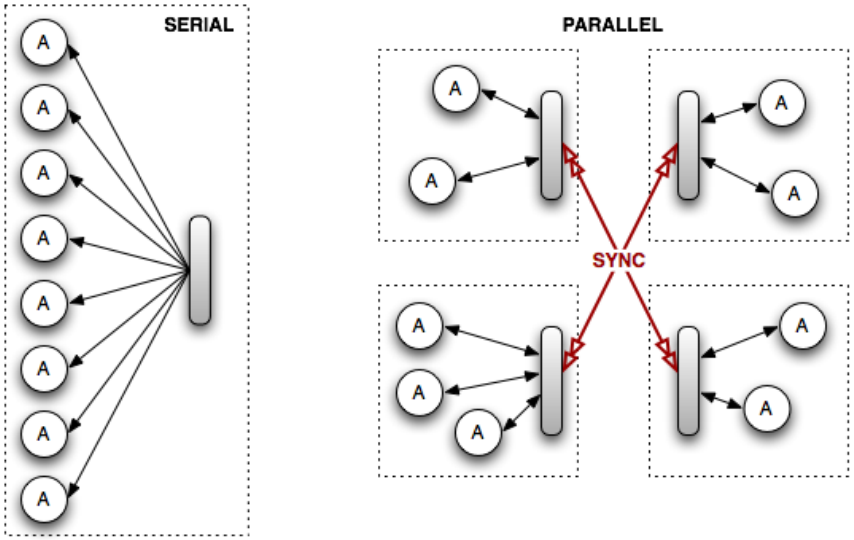
- No direct agent-to-agent communication
  - All communication goes through the message board
  - Use message filters to achieve same effect
- Agents **cannot** remove messages from boards
  - Boards are automatically cleared after each iteration!
- Agents cannot **both** write and read the **same** board within a function (same type of message)
  - Use separate functions. First write, then read.

Parallelism in FLAME

"Agents interact with other agents only through messages"

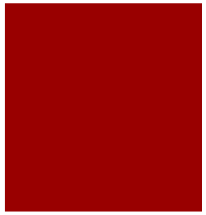
Parallelism achieved by:

- Distributing agents across multiple processors
- Ensuring that agents have equal access to messages



Features of FLAME

- Simple C functions are re-usable blocks of code.
- Use messages for agent communication.
- Agent functions are automatically scheduled and activated (by layers, conditions).
- Message filtering based on agent/message variables.
- C source code linked to XML
- Nested hierarchical models

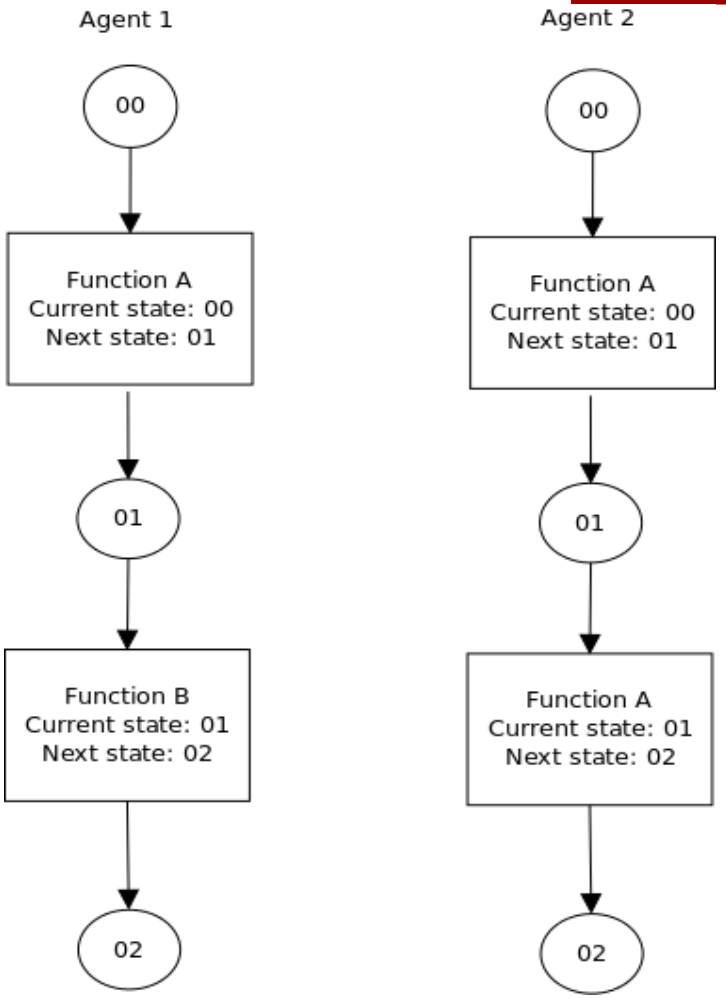


Questions so far?

Tutorial 2:
Functions and stategraphs

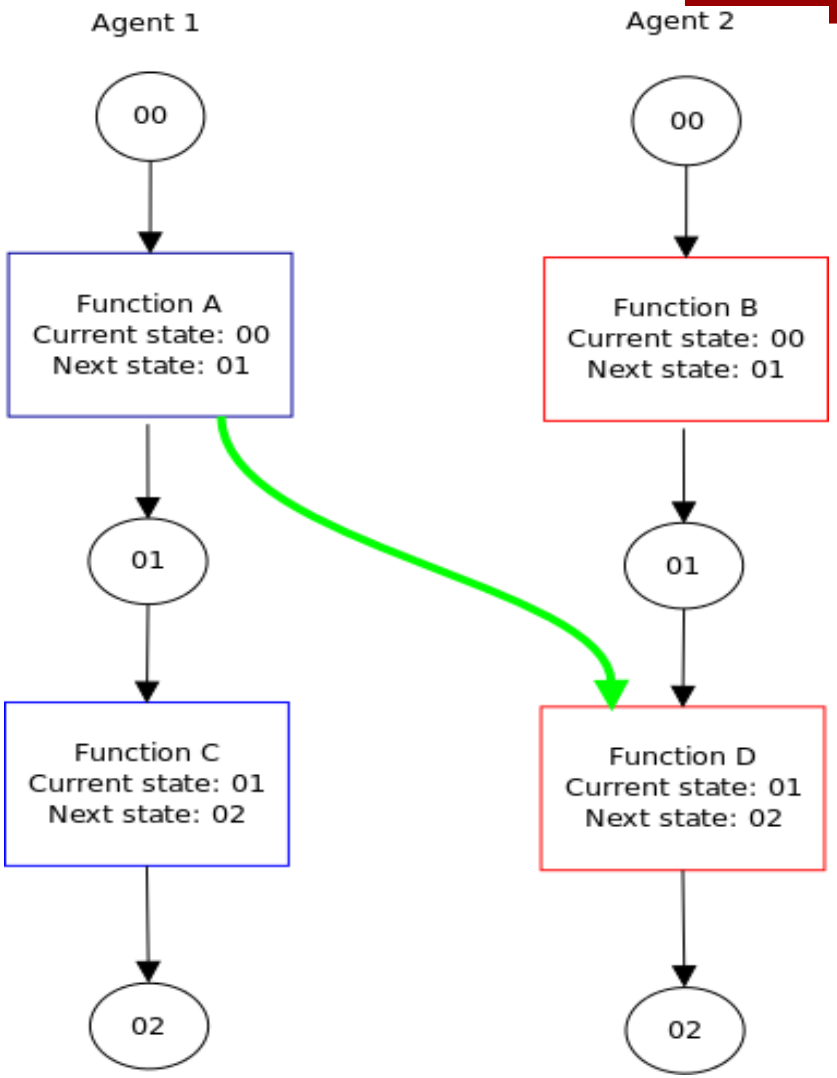
Function stategraph

- Agents are **prototypes**, not individuals! (E.g. Firms, Households, etc.)
- Functions are separated by states
- Modular code: functions can be re-used multiple times in stategraph
- BUT: no cyclical function dependencies!



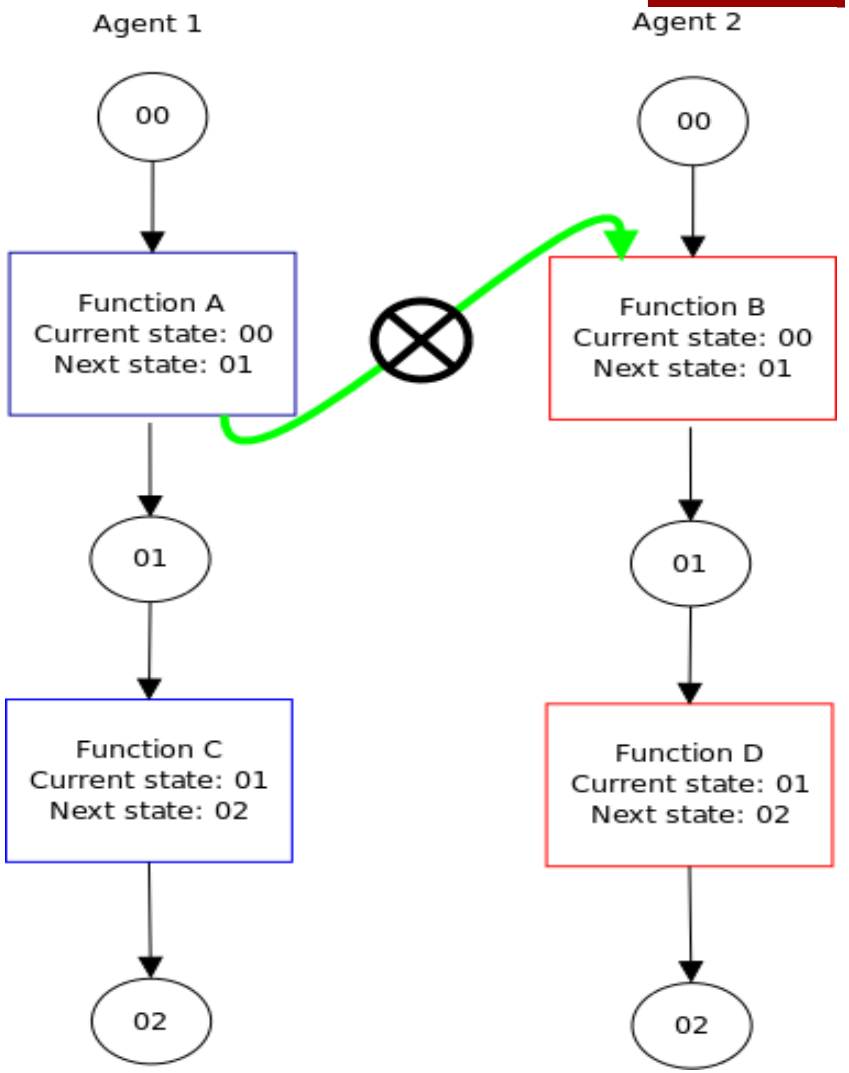
Agent interaction by messages

- Agent type 1, Function A sends a message
- Agent type 2, Function D reads the message
- Sending function is always (!) above reading function
- All agent 1s have to finish Function A before Agent 2s can start Function D.



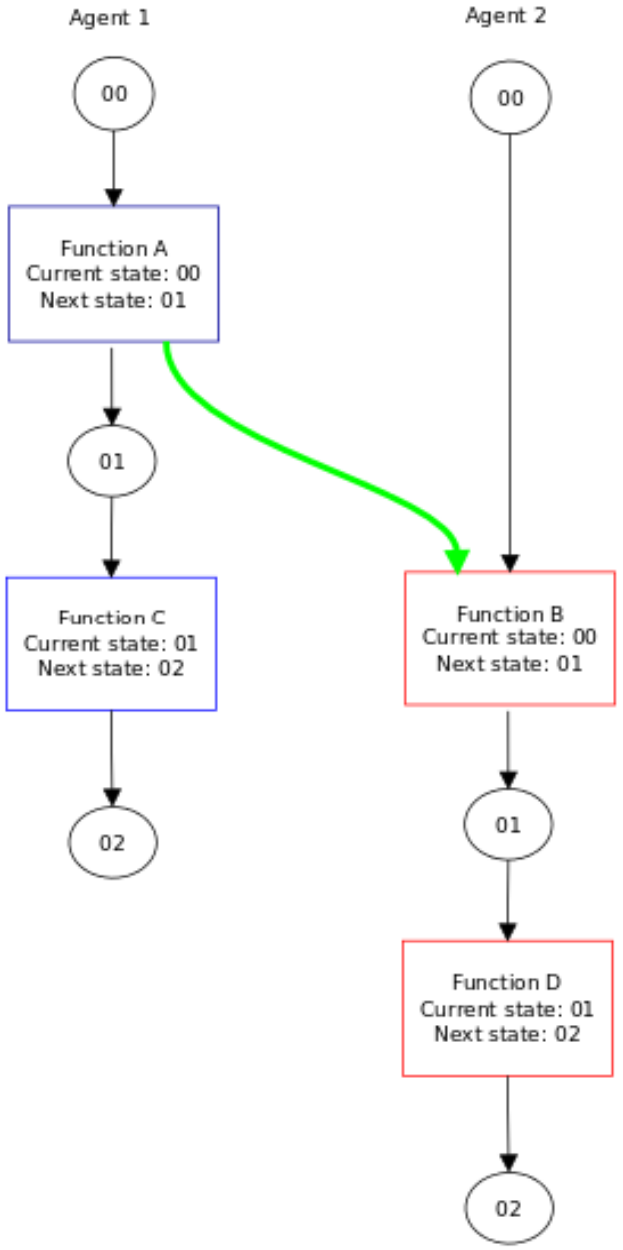
Function layers

- Sending and reading functions cannot be in same function execution layer



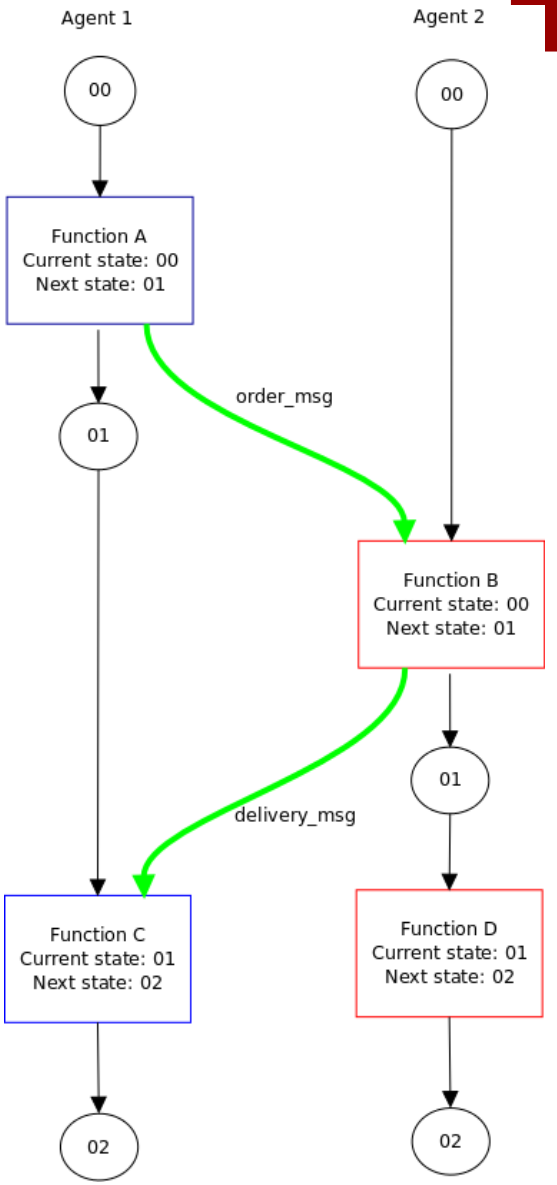
Function layers (2)

- Solution: Function D is shifted down automatically to the next execution layer



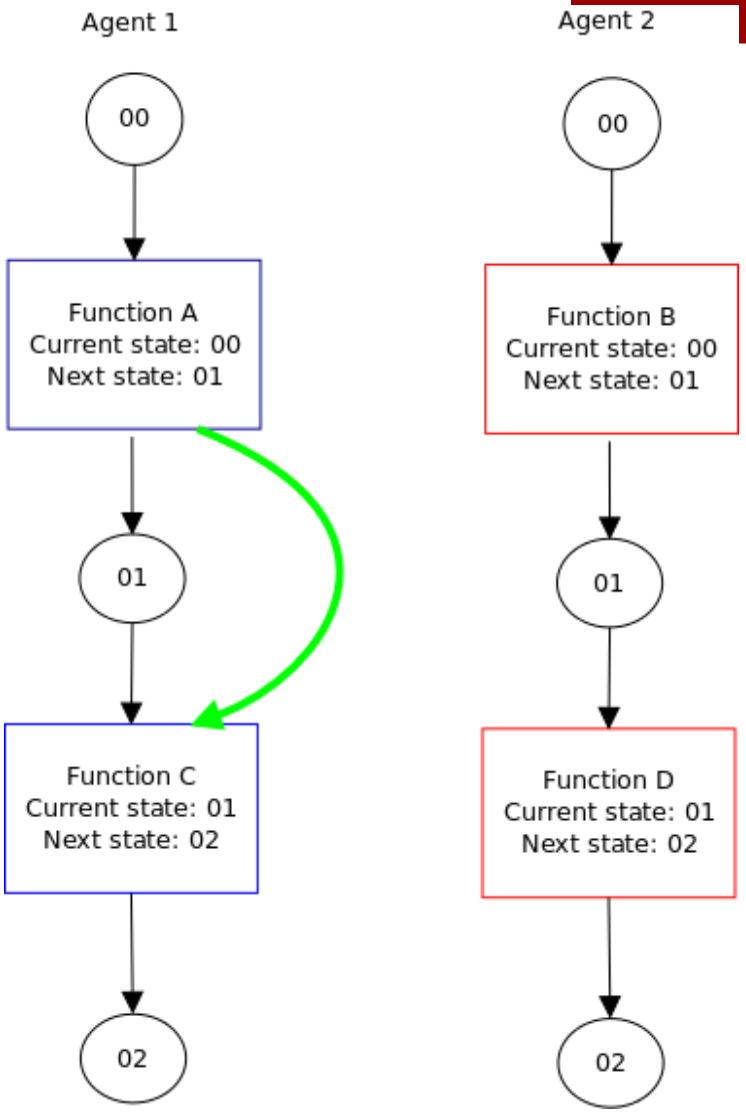
Function layers (3)

- Further shifting occurs by multiple messages



Stategraph

- **Same** agent **type** can also send a message to itself (intra-type communication)
- As long as reading function is below sending function
- Examples:
  - social relationships
  - consumer word-of-mouth
  - inter-firm communications



Tutorial 3:
Main functionality

Learning Objectives

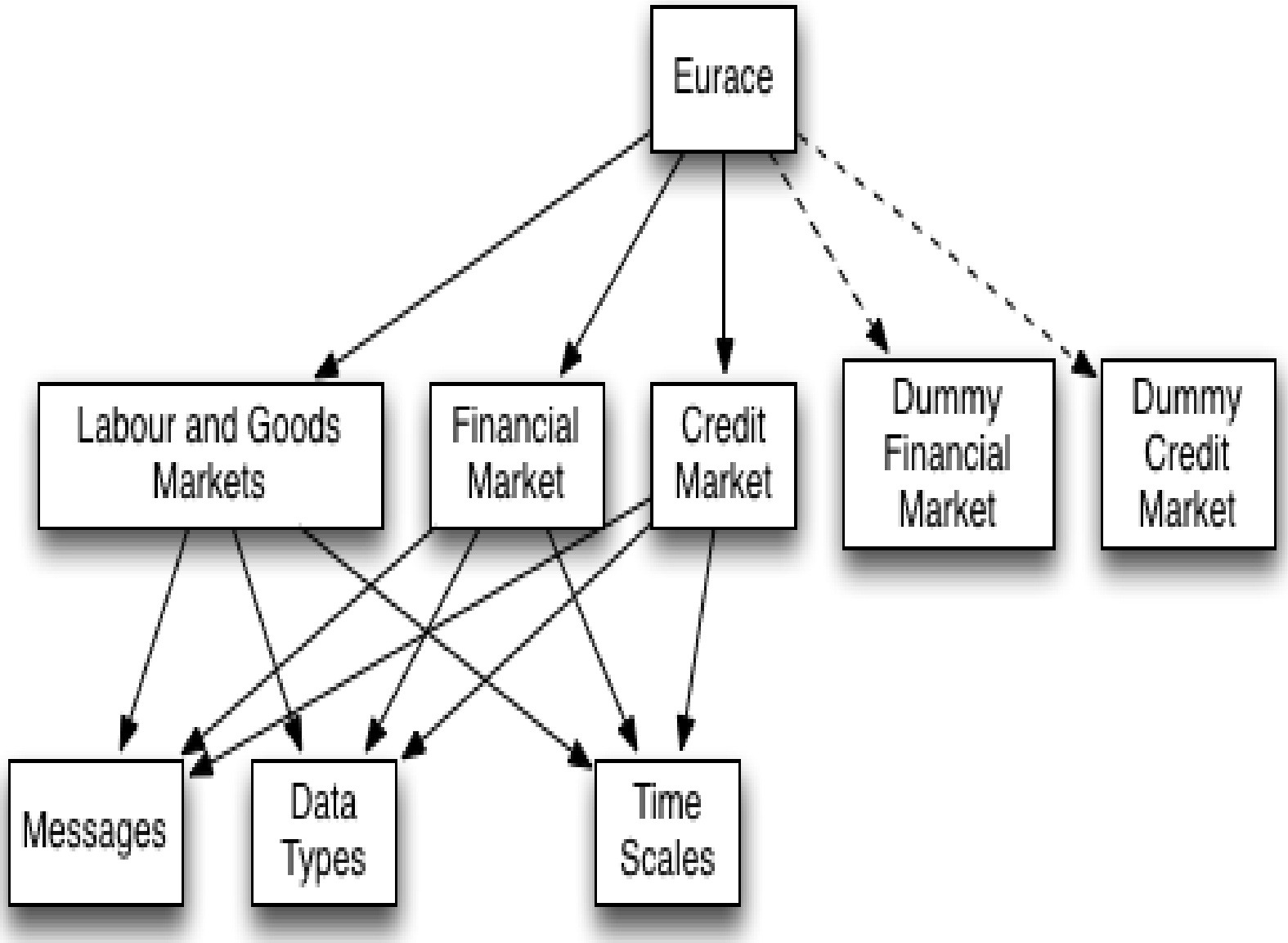
- Overview of XML structure
- Extra features
- Advanced examples

Model structure

- Model description file: **model.xml**
- Header: descriptive part
- Models
- Environment
- Agents
- Message definitions

```
<xmodel version="2" >
 <name>
 <version>
 <description>

 <models>
 <environment>
 <agents>
 <messages>
</xmodel>
```


Eurace
Labour and Goods Markets
Financial Market
Credit Market
Dummy Financial Market
Dummy Credit Market
Messages
Data Types
Time Scales

Nested models

- File: relative path to model.xml
- Enable/disable
- Agents can be defined across

  different nested model.xml files

```
<models>
  <model>
   <file> [Path/model.xml] </file>
   <enabled> [true|false] </enabled>
  </model>
</models>
```

Environment tag

- constants: global parameters
- functionFiles: link in C code
- timeUnits: user-defined
- dataTypes: user-defined

```
<environment>
        <constants>
        <functionFiles>
        <timeUnits>
        <dataTypes>
</environment>
```

Constants

- Defined same as variables
- Type
- Name
- Description

```
<constants>
        <variable>
                <type>
                <name>

<description>
        <variable>
        ...
</constants>
```

FunctionFiles

- **XML:** C source code is linked in by function files

```
<functionFiles>
<file>Source_code_file_1.c</file>
<file>Source_code_file_2.c</file>
</functionFiles>
```

- **C:** In code files, headers are included to link FLAME generated code:

```
#include "../header.h"
#include "../Agentname_agent_header.h"
#include "../my_library_header.h"
```

Time Units

- XML Environment defines time units
- Functions can have time conditions
- Period: periodicity of time unit, based on fundamental time unit **iteration**

```
<timeUnits>

<timeUnit>
 <name>daily</name>
 <unit>iteration</unit>
 <period>1</period>
</timeUnit>

<timeUnit>
<name>monthly</name>
 <unit>daily</unit>
 <period>20</period>
</timeUnit>

</timeUnits>
```

DataTypes

- Similar to C structures.
- Used in agent memory for variables.
- Can be used in C functions as well.

```
<dataTypes>
        <dataType>
        <name>
        <description>
        <variables>
                <variable>
                ...
                </variable>
        </variables>
        </dataType>
        ...
</dataTypes>
```

Agents

- Name (archetype name)
- Description
- Memory
- Functions

```
<agents>
        <xagent>

<name>Firm</name>

<description></description>
                <memory>
                <functions>
        </xagent>
        ...
</agents>
```

Memory

- Variable
- Type
- Name
- Description

```
<memory>
<variable>
        <type>int</type>
        <name>id</name>

<description>...</description>
</variable>
<variable>
        <type>double</type>
        <name>xvar</name>

<description>...</description>
</variable>
</memory>
```

Functions

- Name
- Description
- Current state
- Next state

```
<functions>
        <function>

<name>Agent_Function_1</name>

<description>...</description>

<currentState>00</currentState>

<nextState>01</nextState>
        </function>
</functions>
```

Messages

- Name
- Description
- Variables

```
<messages>
        <message>

<name>Message_Name</name>

<description></description>
        <variables>
        <variable>
                <type>int</type>

<name>firm_id</name>

<description>...</description>
        </variable>
        </variables>
```

Extra features of FLAME

- Simple C functions are re-usable blocks of code.
- Use messages for agent communication.
- Agents are automatically activated (turns).
- Function activation based on time schedules, or event-based.
- Message filtering based on agent/message variables.
- Message pre-sorting, randomization by FLAME

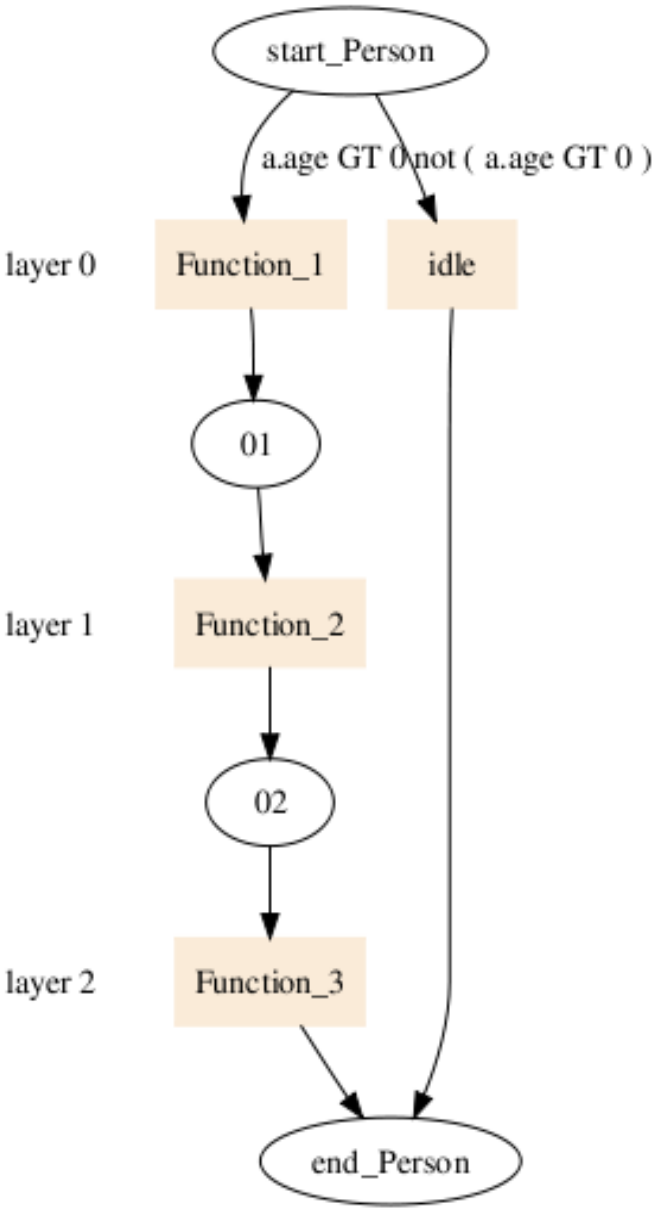
Tutorial 4:
Function conditions

Function conditions

- Functions are activated based on conditions:
  - Time-based: add a time condition
  - Event-based: add a memory condition
- Important note:
  - From every state, all possible branching conditions must be mutually exclusive.
  - From every state, there must be at least one condition that is true (else the agent reaches its end state).

Function activation: memory conditions

```
<function>
<name>
<description>
<currentState>start_Person</currentState>
<nextState>end_Person</nextState>
<condition>
        <lhs>
                <value>a.age</value>
        </lhs>
        <op>GT</op>
        <rhs>
                <value>0</value>
        </rhs>
</condition>
</function>
```



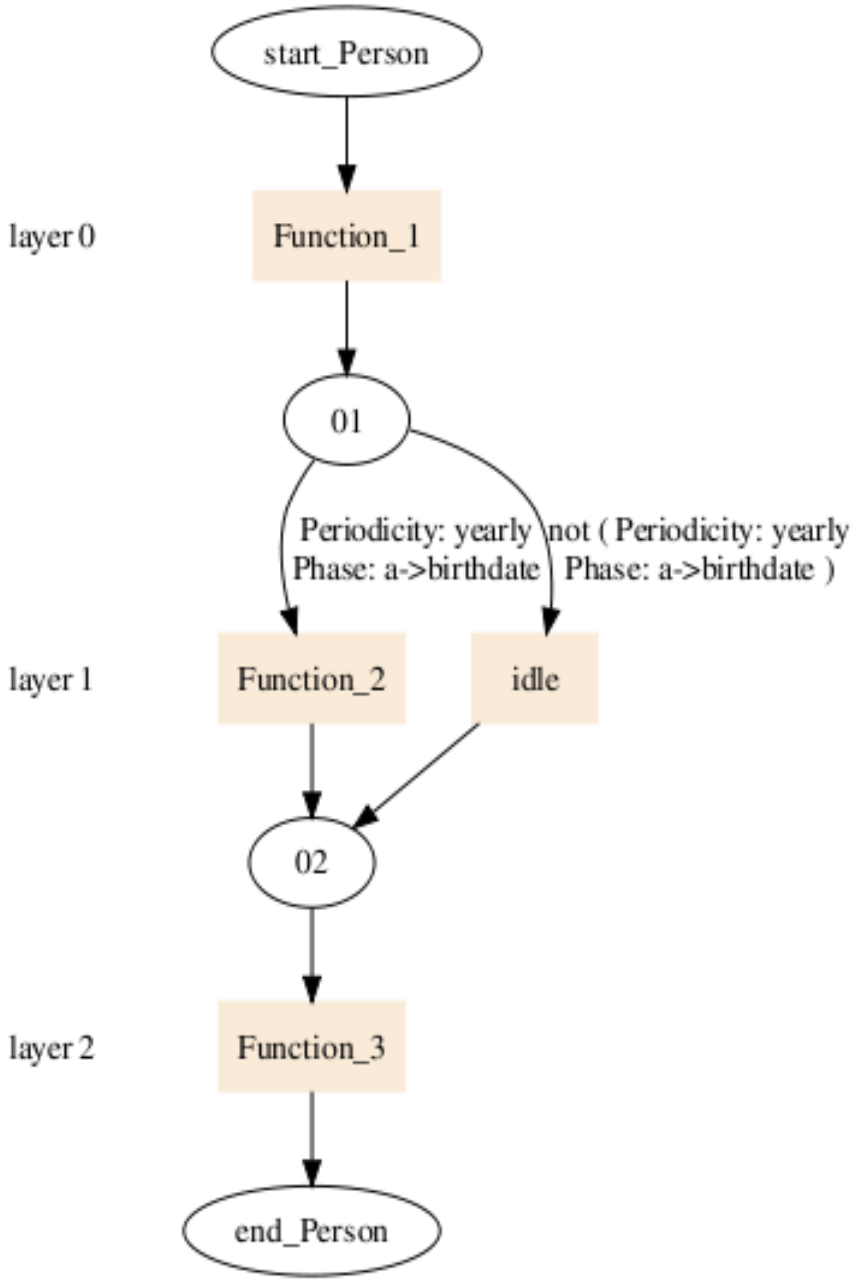
Function activation: time conditions

```
<function>
<name>
<description>
<currentState>01</currentState>
<nextState>02</nextState>
<condition>
        <time>
        <period>yearly</period>
        <phase>5</phase>
        </time>
</condition>
</function>
```

Time conditions can also refer to agent **memory** variables:

```
<condition>
        <time>
        <period>yearly</period>

<phase>a.birthdate</phase>
        </time>
</condition>
```



Messages

- Messages are input/output to functions

```
<function>
        <name>Agent_function_1</name>
        <description>...</description>
        <currentState>00</currentState>
        <nextState>01</nextState>
        <inputs>
                <input>

<messageName>Input_mesg</messageName>
                </input>
        </inputs>
</function>
```

Message loops

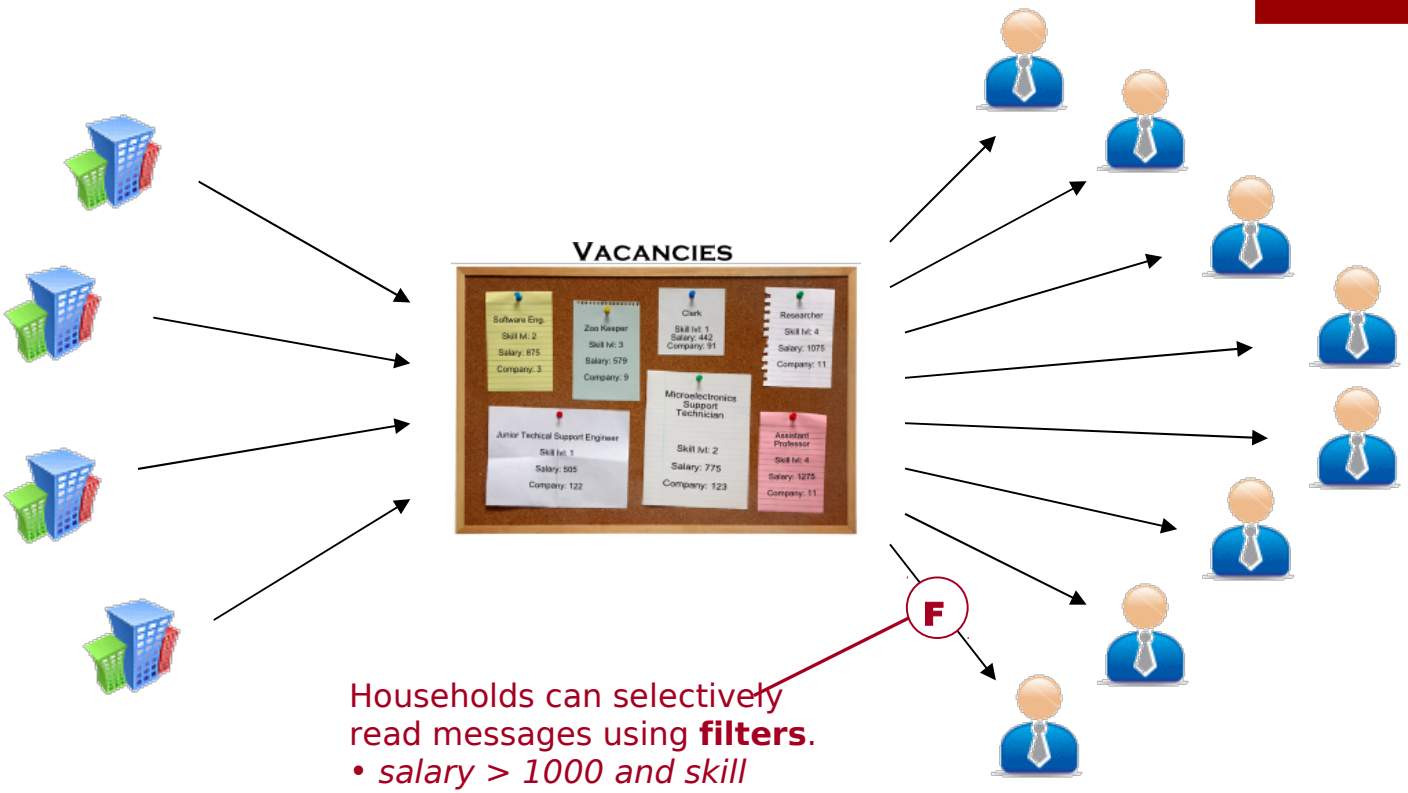
- **C**: Messages are added to the message board

```
add_<messagename>_message(var1,var2,...)
```

- **C**: Agents are looping through the messages

```
START_<MESSAGENAME>_MESSAGE_LOOP
        <Messagename>_message->variables
FINISH_<MESSAGENAME>_MESSAGE_LOOP
```

- Note: **all** messages are processed; filtering **can** be done!



Households can selectively read messages using **filters**.

- *salary > 1000 and skill level = 4*

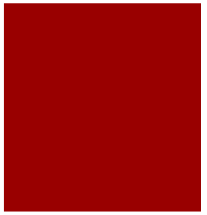
Message filters

- **XML**: Messages can be filtered using filter conditions on the **input** messages
- Filter operators: EQ (==), NEQ (!=), LT (<), GT (>), IN (arrays)
- Use: value of a memory variable (OP) value of a message variable.
- Example:

  ID == message ID

```
<filter>
<lhs><value>a.id</value><lhs>
        <op>EQ</op>
<rhs><value>m.id</value></rhs>
</filter>
```

```
<input>
<messageName>Message_Name</messageName>
        <filter>
        <lhs>
                <value>a.id</value>
        </lhs>
        <op>EQ</op>
        <rhs>
                <value>m.id</value>
        </rhs>
        </filter>
</input>
```



Tutorial 5:
Linking XML and C code

Linking XML to C

- FLAME generated header files included in the C source code
- C source code files are included in the XML model
- C source code:
  - Using memory variables: CAPITALIZED names
  - All memory variables retain their values
  - Looping over messages: FLAME message loop code

- Nested models: can be enabled/disabled in XML

Including Function Files

- Assume: each agent has its own functions file.
- **XML:** C source code is linked in by function files

```
<functionFiles>
<file>Source_code_file_1.c</file>
<file>Source_code_file_2.c</file>
</functionFiles>
```

- **C:** In C source code files, headers are included to link to FLAME generated code:

```
#include "../header.h"
#include "../Agentname_agent_header.h"
#include "../my_library_header.h"
```

Message looping in C

- **C**: Messages are added to the message board

```
add_<messagename>_message(var1,var2,...)
```

- **C**: Agents are looping through the messages

```
START_message_name_MESSAGE_LOOP
    X = <message_name>_message−> msg_var1 ;
    Y = <message_name>_message−> msg_var2 ;
FINISH_message_name_MESSAGE_LOOP
```

- Note: by default **all** messages are processed; however: filtering **can** be done!

Using memory variables

- **C**: Memory variables are capitalized in C to retrieve and assign values:

```
MY_VAR = 0 ;
int x = MY_VAR ;
```

- **C**: Arrays and datatypes:

```
X = MY_ARRAY_VAR[ i ];

x = MY DATATYPE . var1;
y = MY DATATYPE . var2;
```

Summary

- Simple C functions are re-usable blocks of code in the XML model definition.
- Agent functions are automatically scheduled and activated (by layers, conditions).
- Use messages for agent communication.
- Function activation based on time schedules, or event-based (agent variables).
- Message filtering is based on agent or message variables.
- Message pre-sorting, randomization can be done by FLAME.