

## 1. Purpose and Goals

This software simulates economic interactions by representing agents as balance sheets. Each balance sheet tracks individual transactions, where every asset of one agent corresponds to a liability of a counterparty agent. The system evolves over time, allowing us to study payment flows, defaults, and systemic risks etc.

This is important because the representation of economic interactions in current economic models abstracts away from complexities of money. Current approaches include one or more of the following aspects: ex-post, netted-out, static/beginning-of-time-start and aggregate. These aspects abstract money away as they exclude the possibility of temporal mismatch between assets and liabilities, any preexisting relationships, current market liquidity of assets and agent level intra-sectoral balance sheet dependencies. This software will help generally understand how agents of different kinds (firms, banks, NBFIs, households etc) make decisions facing current and incoming settlement constraints, and how they specifically respond to shocks, such as liquidity shortages or defaults, and to test policies for achieving macroeconomic targets.

## 2. Versions

### 2.1 Initial version

The software should be built starting from an **1.0 version** that will include basic features and go on to include additional features in further versions.

- The version 1.0 will allow the user to **set up agents, one by one**.
- For each agent, the user will **define each entry on their balance sheet** in terms of the counterpart agent's correlative entry, time and relevant monetary values.
- All agents will have a basic goal of **meeting their payment requirements** in time, and all agents will **accept a predefined type of asset as means of payment**.
- Once agents, and means of payment are set, they will form **a system** that will **move through a set of timepoints** where the balance sheet entries will be activated at the predefined time point. Thus the balance sheets will change over time as entries activate.
- Upon activation, the liability holder will **either settle** the payment requirement (or delivery requirement) using previously held and accepted means of payment **or default**.
- In the case of default the system will **stop** at a given time point. Otherwise, the system will **run until all of the initially existing liabilities have been fulfilled**.
- Once the system stops running it will **produce analysis of different aspects of the system**.

\*an intermediate **Version 1.5** would allow to program agents to take specific actions beyond the settlement of already existing payment requirements and towards settling future payment

requirements (but will stop short of giving them an additional goal as described below etc) such as issuing liabilities and purchasing existing assets

## **2.2 Later developments**

**Later versions** (2.0 and on) will include additional features:

### Entry related features

Although it will always be possible for the user to define new balance sheet entries from scratch, the software will offer a set of **entry types** (such as loans, deposits, payables, receivables, bonds, etc.)

### User related features

- Ability to turn off and on any of the additional features
- Bulk agent set up
- Input via abstract description of BS entries
- Definition of the level of interconnectedness (among entities with similar/different balance sheets)
- Randomisation set up according to specified parameters
- Agent modeling:
  - Definition of the **goals** of agents in terms of their balance sheets, beyond fulfillment of payment requirements.
  - Definition of how agents obtain **information**
    - about prices and positions of other agents
    - about parameters produced in system analysis (i.e. system parameters) at each point in time
  - Definition of agents' **risk** appetite and strategy in relation to
  - Definition of agent **types** (banks, NBFIs etc) and imposition of requirements on them (whose non-fulfilment will trigger action of entities that enforce relevant requirements) as well as provisioning of specific benefits (whose activation will trigger actions of relevant agents).
    - On the basis of these inputs the software will establish **agents' hierarchy of preferences** regarding types of decisions they will be making (see agent related features below) in a given type of balance sheet position in time.

### Agent related features:

User will be able to turn off, fix in advance or leave it open to agents - based on the previously defined preferences - to engage in:

- More **complex liquidity related decision making** (meeting current requirement, preparation for the future, planning)
- Decision making **when and if to issue liabilities and purchase correlative assets** (beyond the motivation to meet immediate payment requirements i.e. according to their goal, information etc)
- Decision making regarding agents' **defining payment requirements** will either be in terms of means of payment or they will be open to agreement among agents.
- Deciding among **additional ways to meet payment requirements** such as obtaining bank credit, borrowing against their assets as collateral, issuing debt securities or liquidation of assets.
- Decide to engage in **mergers and acquisitions**
- Decide to **create new sub-agents**, sell off sub-agents, and close sub-agents (which entail additional balance sheets).

### System related features

- In the case of **default**, the entity will enter asset liquidation that will be performed as a bargaining sell off to relevant counterparty agents, so that the asset holder that the entity held liabilities towards would be compensated according to a predefined rule based on the type of liabilities.
- The software will provide user with a possibility of pursuing **completeness of the model** according to the set of different criteria: closed economy completeness, world economy completeness, monetary hierarchy completeness, financial market completeness
- External rules such as policy, and their enforcement mechanisms (that can be related to agent types, or imposed on all agents)
- Theoretical hypothesis testing
- **Additional types of analysis:**
  - **Monetary hierarchy analysis:** How do different forms of liquidity interact with each other?
  - **Yield curve analysis:** How are money markets and capital markets connected?
  - **Dealer model analysis:** How are markets and prices established and how do they change?

In later versions the software would allow the user to take the position of an agent (a company, governmental agency etc) and make decisions for them.

The rest of this document addresses Version 1.0

## 3. Components

### a. Agents

Agents are the core entities in the system. Each agent has a balance sheet with individual entries for its assets and liabilities. Agents interact by executing transactions with one another over time, based on pre-existing asset-liability relationships.

Attributes of Agents:

- Name/ID (to identify each agent).
- Balance sheet (consisting of balance sheet entries e.g., loans, receivables, payables).
- Status: Operating/bankrupt

b. Balance Sheet Position

The balance sheet position tracks all of an agent's financial obligations as liabilities and resources as assets at a given point in time.

Contents:

- Assets are represented on the left hand side.
- Liabilities are represented on the right side.

Each balance sheet can be represented in textual and graphical form.

Example of a balance sheet position:

Textual form:

Agent: Bank 1

Timepoint: t1

- Assets:
  - Type: Reserve Asset
    - Counterparty: Fed
    - Amount: \$100
    - Due Date: on-demand
  - Type: Bond Asset
    - Counterparty: Company 1
    - Amount: \$110
    - Due Date: t2
- Liabilities:
  - Type: Deposit Liability
    - Counterparty: Company 1
    - Amount: \$100
    - Due Date: on-demand

Graphical form:



t1	Reserve (FED) (on-demand) \$100	Deposit (Company 1) (on-demand) \$100
	Bond (Company 1) (t2) \$110	

### c. Balance sheet entries

There are two forms of balance sheet entry: **asset and liability** corresponding to resources and obligations of the agent whose balance sheet they appear on.

Financial assets (all types of assets except the non-financial asset type) of one agent always **correspond to liabilities** of a corresponding agent (which cannot be the same agent).

Each entry includes **details** that specify the interaction between asset holding and the corresponding liability holding agent is supposed to occur:

- **type** (e.g., loan, payable, non-financial) - it imposes rules about issuance, transferring, holding and cancelation of given asset-liability pair (in terms of what type of agent can perform these actions and under what conditions - e.g. only banks can issue loans)
- **counterparty** - corresponding agent
- **amount** - a specified non-zero integer.
- **denomination** - specified label of one of the currencies (i.e. means of payment assets-liability pairs)
- **means of payment** - can be specified or unspecified. When specified it is defined in terms of the asset that the liable party provides to the asset holding counterparty.
- **due date** - specified time stamp. It can be the current time point, any time point in the future, or on-demand (i.e. at a time point when the asset holder demands).

The details on the corresponding assets and liabilities of two agents are **identical** (or **fitting** in specific cases such as in receivable-payable).

An exception in terms of entries is the **non-financial asset** type. As assets they do not correspond to anyone's liabilities, thus the details defining the interaction between agents are not specified.

#### Example of an asset of an agent and a corresponding liability of a counterparty agent:

Textual form

- Agent A:
  - Type: Loan Asset
  - Counterparty: Agent B
  - Amount: \$1,000
  - Due Date: t2

- Agent B:
  - Type: Loan Liability
  - Counterparty: Agent A
  - Amount: \$1,000
  - Due Date: t2

Graphic form:

Agent A		Agent B	
Loan (Agent B) (t2) \$1000, deposit or cash			Loan (Agent A) (t2) \$1000, deposit or cash

#### d. Transactions

Transactions represent economic interactions, such as loans, payments, or settlements. It occurs in a defined time point. Each transaction updates the balance sheet positions of the involved agents.

It involves a creation, a modification or a cancellation of a set of corresponding balance sheet entries.

Key Details:

- Agents involved (e.g., Agent A and Agent B).
- Type of transaction (e.g., loan, payment).
- Amount, (means of payment, if it involves a payment), and due date.
- Settlement rules (e.g., if one party doesn't have enough liquidity).

Example:

Text form:

At the t1 Agent 1 purchases a Bond issued by Agent 2 that pays \$110 at t2 from Agent 2 for 105\$ paying with cash issued by the central bank as a non-financial asset.

Graphic form:

Agent 1		Agent 2	
t0	Cash (CB) \$105		

t1	+ Bond (Agent 2) (t2) \$110 - Cash (CB) \$105		+ Cash (CB) \$105	+ Bond (Agent 1) (t2) \$110
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e. Balance sheet system:

A balance sheet system consists of a number of agents whose balance sheet positions are interlocked at the starting point i.e. each financial asset of an agent corresponds to a liability of a counterparty agent.

Example:

Text form:

Agent 1 holds a Bond asset issued by Agent 2 as its Bond liability that pays \$110 at t2. Agent 2 holds a Claim to receive asset for 10 Machines as non-financial asset from Agent 3 at t1 who has issued the promise to deliver liability for 10 Machines as non-financial asset.

Graphic form:

Agent 1		Agent 2		Agent 3	
t0	Bond (Agent 2) (t2) \$110		Claim to receive 10 Machines (Agent 3) (t1)	Bond (Agent 1) (t2) \$110	Promise to deliver 10 Machines (Agent 2) (t1)

f. Temporal transformation of a balance sheet system:

Temporal transformation of a balance sheet system consists of a set of consecutive time points where balance sheet entries fixed at a given time point are executed, so that balance sheet positions are updated accordingly. The next time point ensues only once all of the balance sheet entries for the given time point have been executed.

Example:

Text form:

- t0

- Agent 1 holds a Bond asset issued by Agent 2 as its Bond liability that pays \$110 at t3.
  - Agent 2 holds a Claim to receive asset for 10 Machines as non-financial asset from Agent 3 at t1 who has issued the promise to deliver liability for 10 Machines as non-financial asset.
  - Agent 2 holds a Receivable from Agent 4 for \$110 at t2 issued by Agent 4 as its payable liability.
  - Agent 3 holds 10 Machines as non-financial asset.
  - Agent 4 holds \$110 cash issued by the Central Bank as a non-financial asset.
  - Agent 4 holds a Claim asset to receive 10 Machines at t2 issued as a liability by Agent 2
- t1
  - Agent 3 transfers the 10 machines to Agent 2.
  - Agent 2 extinguishes a Claim to receive asset for 10 Machines as non-financial asset from Agent 3 at t1 who has issued the promise to deliver liability for 10 Machines as non-financial asset. Agent 3 extinguishes the corresponding liability.
- t2
  - Agent 2 transfers the 10 machines to Agent 4.
  - Agent 4 transfers the \$110 Cash to Agent 2.
  - Agent 4 extinguishes the Claim asset to receive 10 Machines at t2 issued as a liability by Agent 2. Agent 2 extinguishes the corresponding liability.
  - Agent 2 extinguishes a Receivable from Agent 4 for \$110 at t2 issued by Agent 4 as its payable liability. Agent 4 extinguishes the corresponding payable liability.
- t3
  - Agent 2 transfers the \$110 Cash to Agent 1.
  - Agent 1 extinguishes a Bond asset issued by Agent 2 as its Bond liability that pays \$110 at t3. Agent 2 extinguishes the corresponding liability.
- =
  - Agent 4 holds 10 Machines as non-financial asset
  - Agent 1 holds \$110 cash issued by the Central Bank as a non-financial asset.
  - Agent 2 has no assets/liabilities
  - Agent 3 has no assets/liabilities

What is the name of the asset/liability

What is the name of the corresponding agent

what is the maturity time point

what is the size of the cashflow

Graphic form:

What are

	Agent 1		Agent 2		Agent 3		Agent 4	
t0	Bond (Agent 2) (t3) \$110		Claim to receiv e 10 Machi nes (Agent 3) (t1)	Bond (Agent 1) (t3) \$110  Promis e to deliver 10 Machin es (Agent 4) (t2) \$110	10 machi nes	Promis e to deliver 10 Machin es (Agent 2) (t1)	Cash \$110  Claim to receive 10 Machin es (Agent 2) (t2)	Payabl e (Agent 3) t(2) \$110
t1			+10 machi nes  -Claim to receiv e 10 Machi nes (Agent 3) (t1)		-10 machi nes	-Promi se to deliver 10 Machin es (Agent 2) (t1)		
t2			+Cash \$110  -Recei vable (Agent 4) t(2) \$110  -10 machi nes				-Cash \$110  +10 machin es	-Payab le (Agent 3) t(2) \$110

t3	+Cash \$110  -Bond (Agent 2) (t3) \$110		-Cash \$110				
=	Cash \$110						10 machines

g. Analysis:

For each balance sheet position of a balance sheet system after the starting point, the software produces five analytical output in forms of labels and indicators.

1. **Balance sheet analysis:** How are economic agents financially interconnected?
2. **Payment-Funding analysis:** Using what means are the payments being made, how are they initially and ultimately funded?
3. **Risk analysis:** What kinds of risks emerge based on their interconnectedness?
4. **Valuation analysis:** How are financial instruments evaluated?
5. **Flux-Reflux analysis:** Is and if yes, how is money created, distributed and dissolved?