Introduction to Lsd

Major features and plan

Marco VALENTE[1,2]

[1]LEM, S. Anna School of Advanced Studies, Pisa

[2]University of L'Aquila

Outline

Objective: learning how to use simulations implemented in Lsd to make research in Economics

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Plan

- **Introduction**: goals and plan of the course

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- **Definitions**: a normal form of a simulation model.
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- **Tutorials**: implementation of increasingly complex example models.

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- **Introduction**: goals and plan of the course
- **Definitions**: a normal form of a simulation model.
- **Introduction to Lsd**: equations, structures and configurations of models.
- **Tutorials**: implementation of increasingly complex example models.
- **Methodology**: How to develop and assess scientific knowledge by means of simulation models.

Why using simulations?

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At the end of the course we will provide a detailed definition of the methodological protocol required by simulations, both in social sciences and in “hard” fields. However, we anticipate the fundamental point of the proposed protocol.

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2. Research models must **explain** reality.

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1. We talk about research simulation models. Other applications may differ.
2. The pivotal concept is what we mean by *reality*. Economic events are ill-defined, lacking direct measures, and never replicate through history.
3. *Explaining* needs a formal definition, too. We will provide one, showing that it is both intuitive and rigourous.

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- Find explanations of interesting simulated events, as if analysing the record of a virtual history
- Evaluate whether the same explanations, *mutatis mutandis*, apply to the real world cases, too.

Simulation models vs programs

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A simulation model may be implemented with a variety of tools: mental experiments, pencil and paper, Excel spreadsheet, etc. Complex models require computer programs, but, in these cases, the most challenging task is to develop the software tools necessary to make sense of massive amounts of data.

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Using LSD, conversely, the modeller focuses only on the model, and the system automatically generates professional tools to control and access any aspect of the model.

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- **Interpretation**: extracting knowledge from simulation models.

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3. Indicate the steps required to use a simulation model.

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Simulation run: sequence(s) of values across simulation time steps. $\{X_1, X_2, ..., X_t, ..., X_T\}$

Definition of simulation models

Notice that we choose to refer to *time driven* simulation models, as opposed to *event driven* models.
The two styles of modelling are equivalent, since one can be turned into the other.

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1. **Univocal**. The definition must be unambiguous, making impossible to include implementations of the same model but generating different results.
2. **User friendly**. It must be as close as possible to (one of) the way(s) people usually refer to models in natural language.

Definition of simulation models

In the following we list the elements composing a simulation model, providing definitions such that no ambiguity is left about the simulation results produced with the model.

Variables

Variables are labels, or symbols, that at ***each time step*** are associated to one and only one numerical value.
The numerical value of a variable is computed executing an *equation*, defined as any computational elaboration of other values.
$X_t = f_X(...)$

Parameters

Parameters are labels associated to numerical values.
Parameters do not change value of their own accord.

α

Functions

Functions are, like variables, numerical values computed as result of an equation. However, the values generated by functions are not associated to time steps, but are computed on request during the execution of other equations.

$X = f(...)$

Objects

In almost any case a model is designed to contain many copies, or instances, of variables, parameters and functions. They share the same label and properties (i.e. equations) but are distinguished and independent from one another.
In mathematical format we normally use vectors, using the same label with different indexes:

$$\vec{X} = \{X^1, X^2, ..., X^i, ..., X^n\}$$

Objects

However, in “hierarchical” models, vector-based representations are extremely annoying. For example, consider a variable supposed to refer to a firm (among many), operating in a market (among many) which is part of a country (among many). Such a variable would need three indexes to be accessed, for the firm, market and country it refers to.

Moreover, troubles emerge when we deal with dynamic models. Adding a new firm requires to extend all the vectors referring to this entity.

Programming languages have developed a more powerful concept, that includes vectors, but it is far more general: objects.

Objects

Objects are containers, storing together different types of elements that are, somehow, forming an identifiable unit. Programming using objects is far simpler (and less dangerous) than using vectors. Moreover, objects are particularly useful for simulations, since the unit representing an object can easily be associated to the real-world entity that the model refers to.

Definition of simulation models

Object-based representations are equivalent to a matrix-based representation.

		Object-based			
		$ObOne^1$	$ObOne^2$	...	$ObOne^N$
Vector-based	$\vec{X}$	X^1	X^2	...	X^N
	$\vec{Y}$	Y^1	Y^2	...	Y^N
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Object-based representations are far more flexible than vectors, easily expressing, for example, the equivalent of nested matrices and matrices with different number of rows in each column.

Model Structure

In summary, we can call the **structure** of a model the set of the following elements:

1. **Variables**. Symbols associated to a single value at each time step, computed according to a specified equation.
2. **Parameters**. Symbols associated to values not changing of their own accord.
3. **Functions**. Symbols providing values computed by an equation on request by other equations (independently from the time).
4. **Objects**. Units containing a set of other elements.

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The structure of a model is still an ambiguous description, since the same structure will, in general, produce different results depending on the numerical values assigned at $t = 0$. Let's see which numerical values for each type of element can affect the results.

Model Configuration

The first numerical value is the **number of objects**, since it also determines the number of other elements.

Notice that the assignment of objects' numbers may be quite elaborated, with different number of entities for different "branches" of the model.

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At time $t = 1$, the very first step of the simulation, the equation becomes:
$X_1 = Y_0 + \alpha$
Y_0 cannot be produced by the model, since 1 is the first time step. Consequently, the modeller that must assign to Y a *lagged* (or past) value for Y as part of the initialization of the model.

Model Configuration

An equation may also require more than one lag. Consider, for example, the following equation:

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Functions also may require “lagged” values, though they do not refer to previous time steps, but to previous calls, or executions, of the function’s equation.

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  - **Sim. settings**: num. of time steps, num. of simulation runs, pseudo-random sequences, visualization and saving options.

LSD simulation models

LSD allows users to generate a simulation program defining only the elements of a simulation model according to the format proposed above.

Furthermore, LSD provides programs complete with interfaces, debugger, graphics etc. allowing the full analysis of the results.

Using models in practice

Though we will discuss the methodology of simulations for research at the end of the course, it is worth mentioning practical suggestions that we will derive. That is, we briefly review what type of activities a researcher is required to perform.

These are somehow similar to that of a programmer, though the researcher has a further requirement: understand how its model works and present its content (model and result) to scrutiny.

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6. **Revise and extend**: modify 1, 2, 3, 4 and 5, and expand the model when satisfied.

Using models in practice

The success of a project depends crucially on the adoption of a **gradual** approach. A model should initiallly implement a tiny part of the elements one eventually wants to place in the model. Only when the implemented part is tested and its behaviour fully understood, then a new module may be added.

Writing in one shot the whole model, is a sure recipe of failure. Most likely, the model will be so full of bugs, that fixing them will be impossible. Furthermore, even in the case that the bugs are removed, the model behaviour will have no chance of being interpreted and understood.

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A simulation program requires a long list of computationally complicated *technical* code. Such code does not concern the model directly, but make possible for the model to run on the computer, and its results to be readable by humans.

LSD goals

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- Unexpected results can be reproduced, investigated and clarified.
- ...

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LSD users define independently the different parts of the model, and the system assembles them in a program generating fast and flexible simulation runs, or detailed error messages.

Crucially, the elements in the model are considered as separated modules, that the system assembles as required. It is therefore extremely simple to develop, assess and revise a model implemented with LSD.

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At run time the *Lsd Simulation Manager* re-arranges the equations calling them as necessary to perform the necessary computation.

LSD's equations major features

LSD is endowed with an **automatic scheduling**. The modeller needs not to consider when a particular equation is executed within a time step. The *LSM* automatically (and constantly) re-arranges the order as implied by the equations.
For example, consider the following "model":

$$\begin{aligned} X_t &= F_X(Y_t) \\ Y_t &= F_Y(X_{t-1}) \end{aligned}$$

The system interprets the equations so that Y must be updated before X. Changing order of execution entails simply to change the index for the lags within the equations' code.

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In general a model contains many copies of each element, say many Market's may contain each many Firm's etc. In a simulation run it must be ensured that each copy of a variable makes use of the "correct" copies of the elements required in its equations. As, for example, $Q^i = f(K^i, p^j)$.

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LSD is an object-based language, and therefore it is impossible (besides impractical) to use indexes. By default, LSD finds automatically the "correct" copy of the elements to use in an equation, using a **automatic tagging** system to retrieve required elements.

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In practice, a LSD model is made of individual modules (the equations) which are related only by the labels of the elements required for the computation.

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Finally, LSD is built on standard C++ so that any command or external library compatible with GNU C++ can be used within the model.

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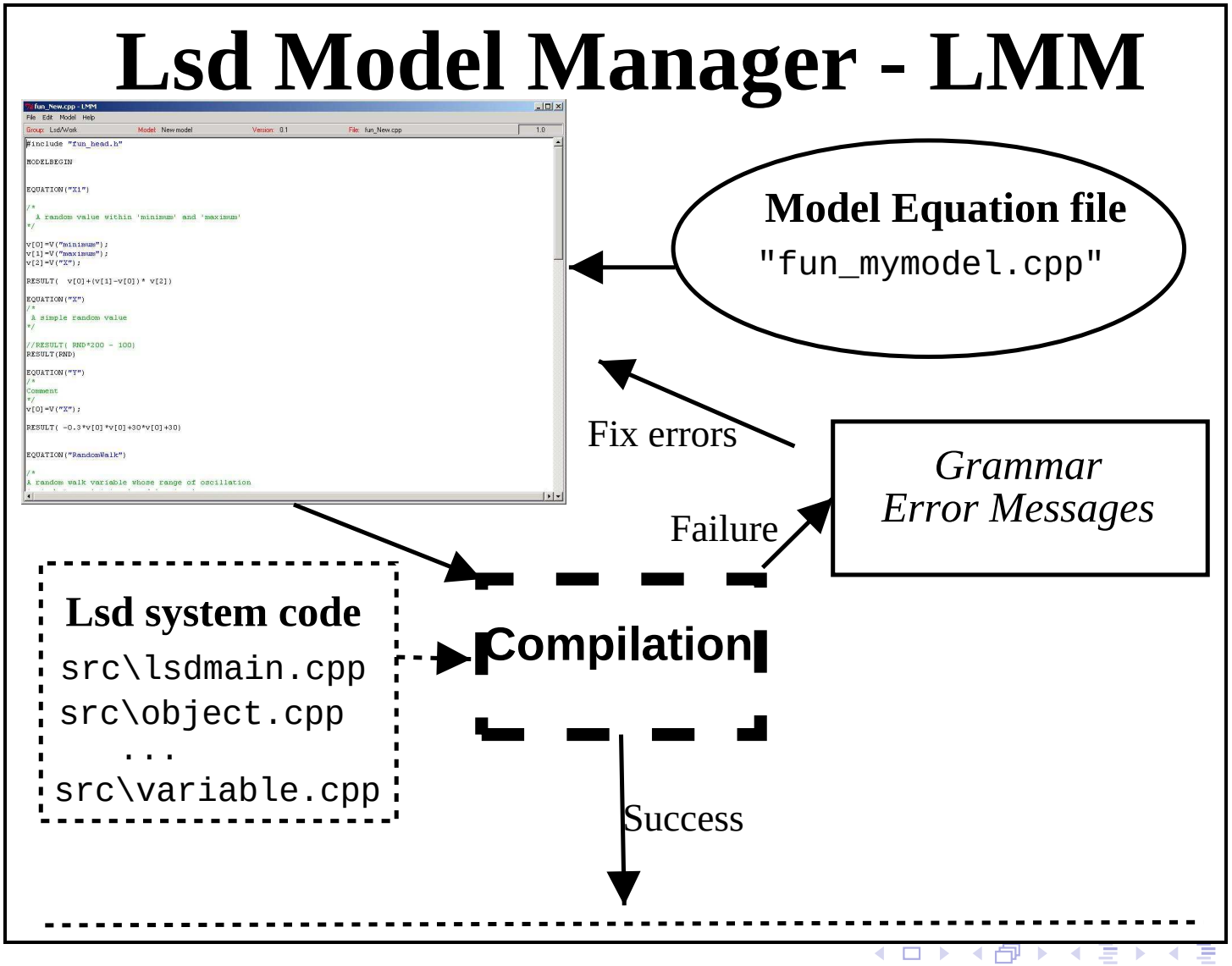
2. Assist in the writing of the equations.
3. Manage the compilation process.
4. Provide indications on grammar errors in the equations' code.

LSD technical components



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6. Document a model with its own interfaces, or exporting reports in HTML or Latex format

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