Lecture 4: Introduction to
[Computer Simulation]
Contents

• Types of simulation
  – Artificial life
  – Discrete-event simulation
  – Bayesian networks
  – Dynamic feedback models

• Simulation topics
Artificial life simulation

Common features:

- Population of agents/individuals
- 2D (or 3D) environment
- Reproduction & evolution
- Emergent complex behavior:
  micro $\Rightarrow$ macro-behavior

Uncommon feature:

- Physics and chemistry of microworld (A Dorin)

Applications (at Monash):

- Ecological modeling (Dorin & Korb)
- Evolution theory (Korb & Nicholson)
- Epidemiology (Dorin, Korb & Nicholson)
- Computer art (McCormack & Dorin)
- Ant colony optimization (Meyer)
- Ethics (Korb & Nicholson)
An ALife Simulation

Let’s suppose we want to do an epidemiological model. There are two organisms with various traits of interest:

- **Host**
  - Strength of immune system
  - Energy/health; death at 0

- **Bacterium**
  - Virulence (health consumption per step)
  - Reproductive traits
  - Infectiousness
An ALife Simulation

Formal Methods II
An ALife Simulation

Chromosome per organism describes its basic abilities and traits:

- Behavior probabilities (Move, Eat, Infect, etc.)
  Function of agent’s percepts
- Health donation to children
- Virulence/immune strength
- Infectiousness

Reproduction:

- Health threshold (= donation)
- Sexual: chromosome crossover + mutation
- Asexual: mutation + DNA exchange

Simulation operation:

1. GENERATE RANDOM POPULATIONS;
2. LOOP: GENERATE RANDOM PERMUTATION OF AGENT LIST;
3. EXECUTE AGENT ACTIONS;
4. KILL OFF ZERO HEALTH AGENTS;
5. COLLECT STATS; GO LOOP;
An ALife Simulation

Note that what is explicitly programmed is only basic behaviors and traits.

Higher level behaviors and traits may emerge. Possible examples:

- Coevolution of immune strength and virulence ("arms race")
- Self-regulation of disease (highly virulent diseases kill themselves out)
- Relation btw virulence and infectiousness
- Ostracism of the ill (if percepts allow)
- Altruism: aiding the ill (e.g., health donation to bolster other’s immune system)

So, ALife sim can be (is) used to investigate hypotheses about virulence of disease, evolutionary defences to disease, etc.

**Time management:** sim steps through time; agent list is randomized at beginning of each time step to avoid evolution of order dependencies.
Pick up the telescope and turn it around:

- Basic unit of simulation is neither time nor agents but
  - Events

- Events occur (or, finish, really) in their own sweet time, whenever they are ready.

- Time is *not* stepped, but added to
  - The next finishing event adds its duration to time
  - No need to simulate anything between the completion of two events

- Nothing evolves; all features (high and low) must be explicitly programmed.
Time Management

Robyn’s datacomm analogy. There are two ways to keep a daisy chain of equipments happy:

- Polling: ask each in turn if it has something to send.
- Interrupt: each one that wants to send a message sends an interrupt requesting permission.

Former is like time stepping in ALife; latter is like event completions in discrete event simulation.
Bacterial Infection

Since features must be explicitly represented it is a bit much to simulate an entire epidemic using DES. Instead, let’s simulate a local infection with the object types:

- Killer T cells
- Bacteria

Bacteria consume energy from the host and (given enough energy) reproduce (asexually). If host energy drops to zero, the host dies. If there are enough T cells, the infection (probably) dies.

Event types (distribution):

- B arrival (Poisson $\lambda_a$)
- B killed (Poisson $\lambda_b$)
- Energy consumption: pseudo-event (lazy)
- Energy production: pseudo-event (lazy)
- B reproduction: pseudo-event (lazy)
Bacterial Infection

System variables:

- System energy
- Time
- T cells
- Bacteria
- Event list: linked list sorted by time

Simulation operation:

1. INITIALIZE;
2. LOOP: EXECUTE NEXT EVENT;
3. PERFORM LAZY CALCULATIONS;
4. UPDATE SYSTEM VARIABLES (INCL TIME);
5. COLLECT STATISTICS;
6. SCHEDULE FUTURE EVENTS;
7. GO LOOP;


Bacterial Infection

Planning the future: what to schedule depends on what just happened and the state of the system.

- If current event is B arrival, schedule the next arrival using $\lambda_a$.
- If new B reproduced or arrived, then assign any idle T cells and schedule deaths with $\lambda_b$.
- If current event is B killed, some T cell is now idle; assign T cell to any available B and schedule death.

All newly scheduled events are then slotted into the event linked list.
Bacterial Infection

In this simulation the two statistics of primary interest will be host energy and bacterial population size. At the end of the simulation you might produce something like this:
Queuing Systems

Queuing systems generalize the kind of simulation described above.

E.g., a single-server queuing system with FIFO service — for example, MS DOS. Distributions:

- “Customer” arrivals (typically, Poisson)
- Service completions (typically, Poisson)

Measurements of interest:

- Ave customer time in system
- Ave time waiting for service
- Ave time server is idle
Bayesian networks (causal models) are graphical (dag) representations of probabilistic (causal) systems. Used for:

- Probabilistic reasoning
- Planning
- Decision making
- Expert systems

They can be used to simulate causal systems, e.g., to predict the result of interventions
Dynamic Models

These include:

- Numerical Weather Prediction (NWP) models
- Local climate models
- Global climate models
- Macro-economic models
- Social models

Combine numerical models of cells with dynamic feedback loops (e.g., water cycles, carbon cycles, money cycles)
Limits to Growth

A notorious early example of computer modeling.

- The Club of Rome’s *Limits to Growth*, (LTG) 1972. Result of computer study by MIT team of 17 researchers.
  - Sold 30 million copies
  - Report from computer model of world economy, population, pollution, natural resources, agriculture (60+ major variables)
  - Basic conclusion: total collapse before 2100
  - Launched decade-long controversy
Basic argument:

1. The natural growth of economy is linear technology accumulates, rather than multiplies
2. The natural growth of populations is exponential organisms multiply
3. \(\therefore\) any population will overrun its capacity
4. \(\therefore\) the natural state of humanity is misery

Most common criticism: Malthus failed to take into account our ability to lift the green and suppress the blue. This criticism is false.
LTG

LTG codifies Malthusian ideas in a computer simulation incorporating 20th C economic theory, etc.

[ copyright figure deleted]
LTG

LTG codifies Malthusian ideas in a computer simulation incorporating 20th C economic theory, etc.

[ copyright figure deleted]
LTG

LTG codifies Malthusian ideas in a computer simulation incorporating 20th C economic theory, etc.

[ copyright figure deleted]
Criticisms of LTG

- Assumptions were pessimistic
- Nothing more than a glorified mental model; objectivity of computer simulations is both persuasive and illusory
- Precision of predictions is misleading
- Incredibly ambitious, ambition beyond our abilities to empirically validate the model

⇒ LTG more or less lost the fight, largely rejected/neglected
A Modest Defence of LTG

- Such modeling allows a systematic exploration of implications of assumptions/theory
- Such models can be verified by empirical testing (e.g., analogous scenarios, early indicators)
- Accuracy of predictions (legitimate degree of precision) subject to statistical verification
- Models can also receive theoretical support (e.g., economic assumptions derived from theory)

The specific modeling of LTG has missed crucial 21st C phenomena:

- Global warming
- Other pollution has been much less serious
- Population growth has been somewhat less

Main defence: specifics are not to the point, basic behavior of the model is. Main message of LTG: global population, environmental & economic planning is necessary.
Simulation topics

In later weeks we will examine all of:

- Pseudo-random number generation (RNG)
- Generating random variables (sampling from various probability distributions)
- Monte Carlo methods
  - Monte Carlo estimation
  - Simulated annealing
- Statistics – crucial for empirical verification/validation of our models