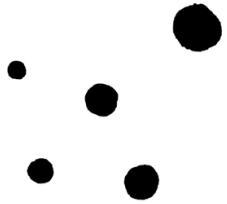

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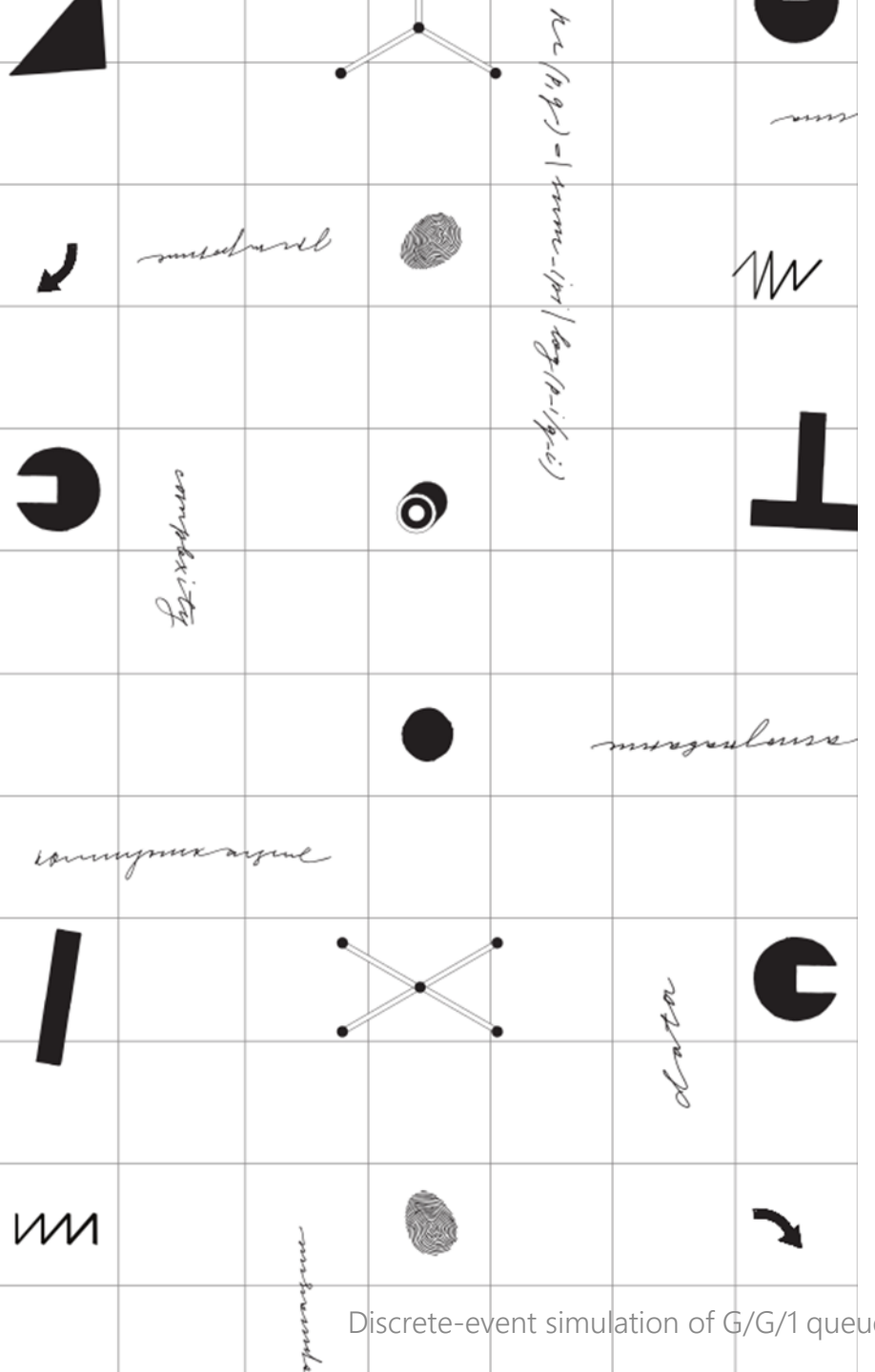
Discrete-event simulation of G/G/1 queueing system

Network simulation practicum

Senior researcher @ Wireless Networks Lab

Andrey Belogaev



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Discrete-event simulation

in C++ custom simulation platform

Events

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Each event has the following properties:

- Unique identifier
- Moment of *model time,* in which the event happens
- Sequence of actions (function) that should be executed (called) in that moment

During the execution of the event's actions new events can be created, and/or some events can be cancelled.

Event queue

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Event queue should be sorted in the ascending order of time moments when these events happen.

$$t1 \le t2 \le t3 \le \ldots \le tN$$

(ID#1, t1, func1)	(ID#2, t2, func2)	(ID#3, t3, func3)	...	(ID#N, tN, funcN)

```
func1 (args) { ...
    if <condition 1> {
        create new event (ID#M, tM, funcM)
        delete event (ID#J)
    }
...}
```

Data structure?

Event queue

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Event queue should be sorted in the ascending order of time moments when these events happen.

$$t1 \le t2 \le t3 \le \ldots \le tN$$

(ID#1, t1, func1)	(ID#2, t2, func2)	(ID#3, t3, func3)	...	(ID#N, tN, funcN)

```
func1 (args) { ...
    if <condition 1> {
        create new event (ID#M, tM, funcM)
        delete event (ID#J)
    }
...}
```

Data structure?

std::map<t, event>

Terminating event

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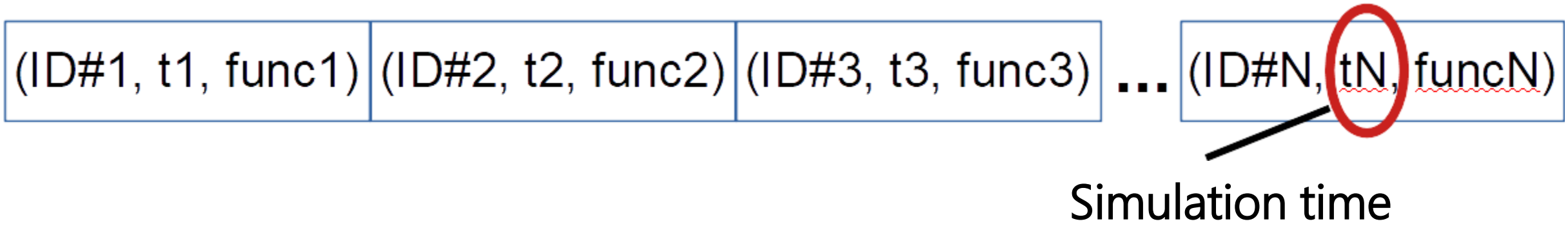
The last event that finishes the simulation.

After this event:

- all remaining events in the queue are deleted;
- the memory allocated for different data structures/objects is freed;
- calculation and saving of output statistics is done.



Callbacks

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Description: server sends packets every *gap* seconds.

Class **Simulator**

Methods:

ID Schedule (t, func)

Fields:

std::map<t, func> queue

Class **Server**

Methods:

```
Send () {
    send packet;
    Schedule (gap, Send);
}
```

Fields:

Time gap

Class Simulator does not have any field of type Server. How to call function Send?

Callbacks

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Description: server sends packets every *gap* seconds.

Class **Simulator**

Methods:

ID Schedule (t, func)

Fields:

std::map<t, func> queue

Class **Server**

Methods:

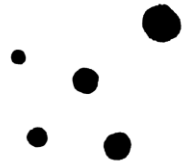
```
Send () {
    send packet;
    Schedule (gap, Send);
}
```

Fields:

Time gap

std::function<void ()> func = std::bind (&Server::Send, this)

Callbacks



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Passing arguments to a function:

Class **Server**

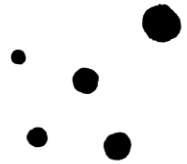
std::function<void ()> func = std::bind (&Server::Send, this, *packet*)

Simulator::Schedule (gap, func); //this is a static function (!)

Class **Simulator**

```
while (!queue.empty && event is not terminating) {
    auto func = queue.begin () → second;
    func (); //packet is already passed to the function with std::bind
    queue.erase (queue.begin ());
}
```

Random variables



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An important property of the scientific experiment is its reproducibility, i.e., the ability to reproduce the same results after the second execution of the same code.

Pseudorandom numbers sequence is a sequence of generated by an algorithm numbers, that are statistically close to numbers generated from uniform distribution. From this sequence one can generate numbers from any other distribution (exponential, gaussian, etc.).

```
std::mt19937 engine (seed); // seed – number that defines the sequence
std::uniform_int_distribution<int> num (0, 99);
std::cout << “Hello, ” << num(engine) << “ world!” << std::endl;
```

“Smart” pointers

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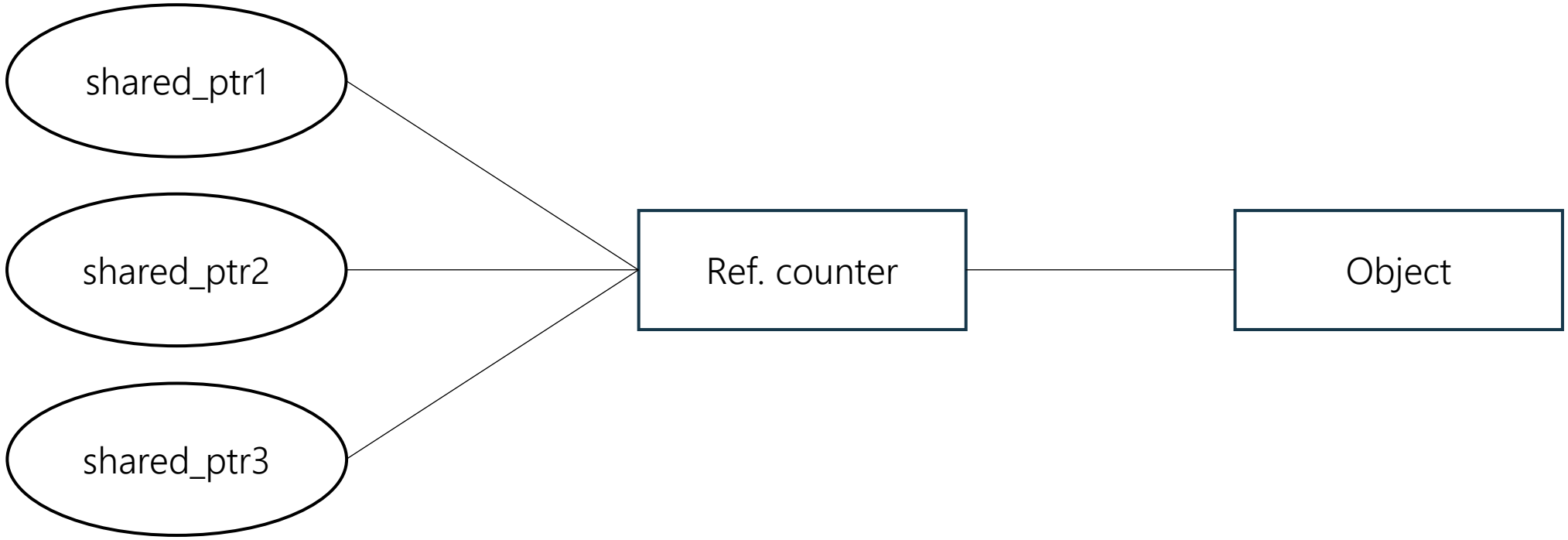
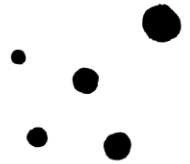
std::shared_ptr<Object> obj (new Object ());



When reference counter becomes 0, the object is automatically deleted.

Scenario (main file)



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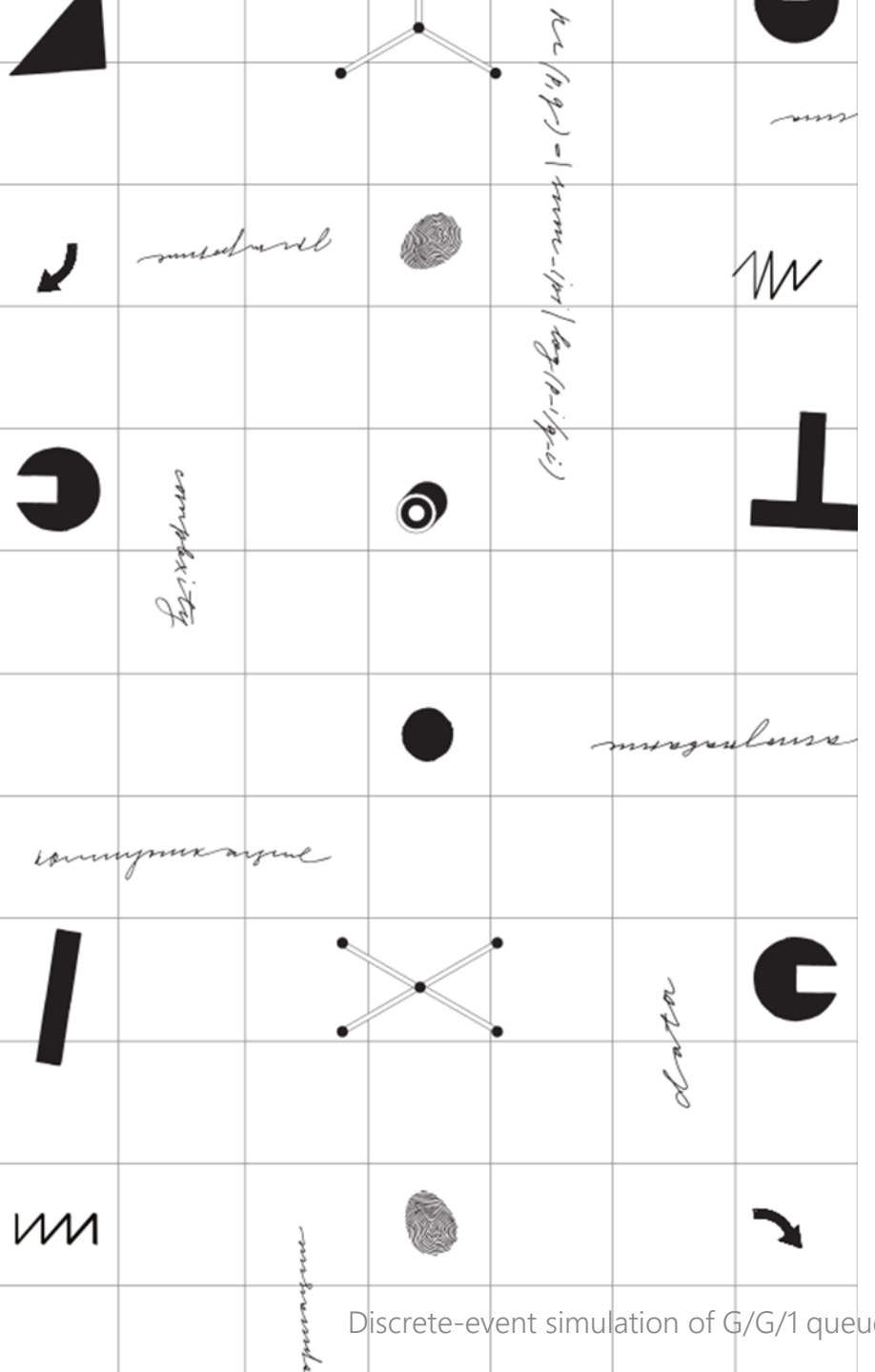
```
int main () {
  …
  Simulator sim;
  sim.Schedule (initial events);
  sim.Schedule (terminating event);
  sim.SetSeed (seed); // seed of pseudorandom numbers generator
  sim.Run ();
  …
}
```



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Modeling of G/G/1 queueing system

G/G/1 queueing system

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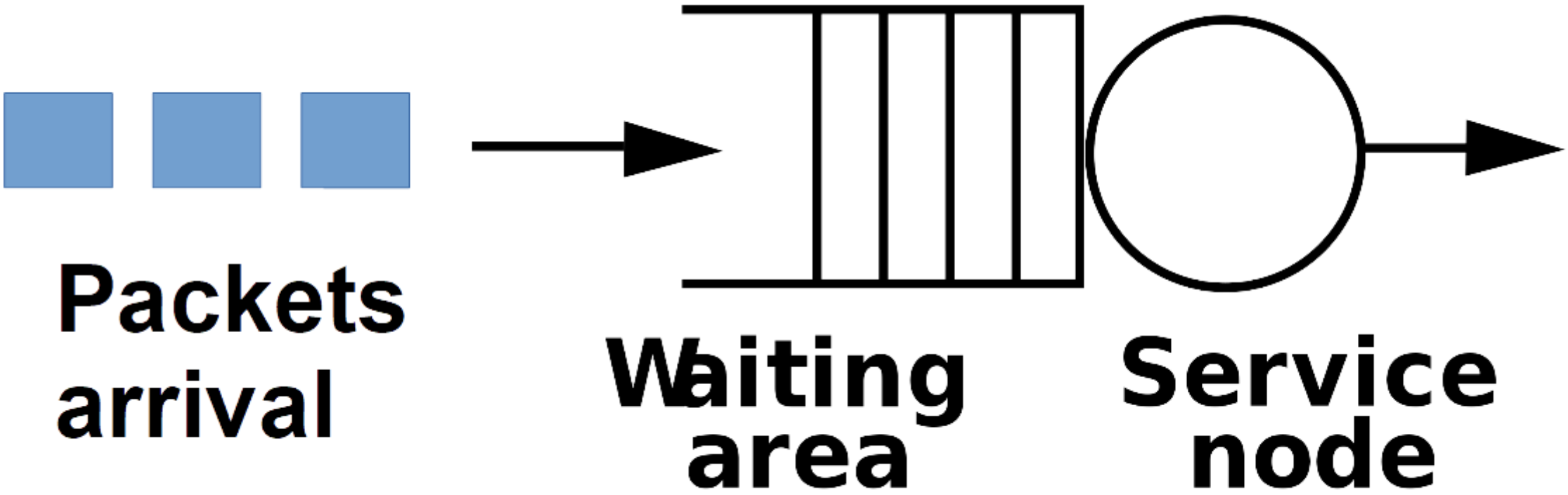
Inter-packet interval and service time are random variables following some arbitrary (General) distributions.



Class Packet

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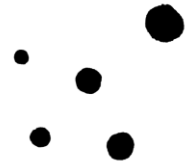
```
class Packet {
  ...
  Time arrivalTime; // time when the packet appears
  Time serviceTime; // time needed to process the packet
  ...
};
```

Class PacketGenerator



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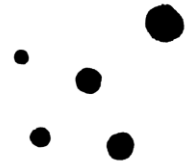
```
template <typename distr1, typename distr2>
class PacketGenerator {…
  void Start (); // for transmission of the first packet
  void NewPacket ();
  distr1 arrival; // for inter-packet interval
  distr2 service; // for service time
  std::shared_ptr<Server> m_server;
};
```

Class PacketGenerator



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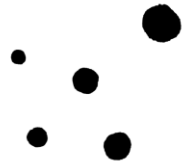
```
template <typename distr1, typename distr2>
void PacketGenerator<...>::NewPacket () {
  // create packet
  std::shared_ptr<Packet> p (new Packet (now, service () ));
  // add packet to server
  m_server → addPacket (p);
  // create callback to this same function NewPacket
  auto callback = std::bind (<...>::NewPacket, this);
  // schedule self-call after inter-packet interval
  Simulator::Schedule (arrival (), callback);
};
```

Class Server



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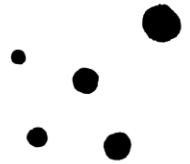
```
class Server {
  …
  void AddPacket (std::shared_ptr<Packet> packet) {
    m_queue.AddPacket (packet);
  }
  Queue m_queue;
};
```

Class Queue



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```
class Queue {
  void AddPacket (std::shared_ptr<Packet> packet) {
    m_queue.push_back (packet);
    if (m_queue.size () == 1) {// only 1 packet in the queue
      Schedule (packet→serviceTime, RemovePacket);}
  }
  void RemovePacket () {
    m_queue.erase (m_queue.begin ());
    Schedule (m_queue.front()→serviceTime, RemovePacket);}
  std::vector<std::shared_ptr<Packet>> m_queue;
};
```

Scenario

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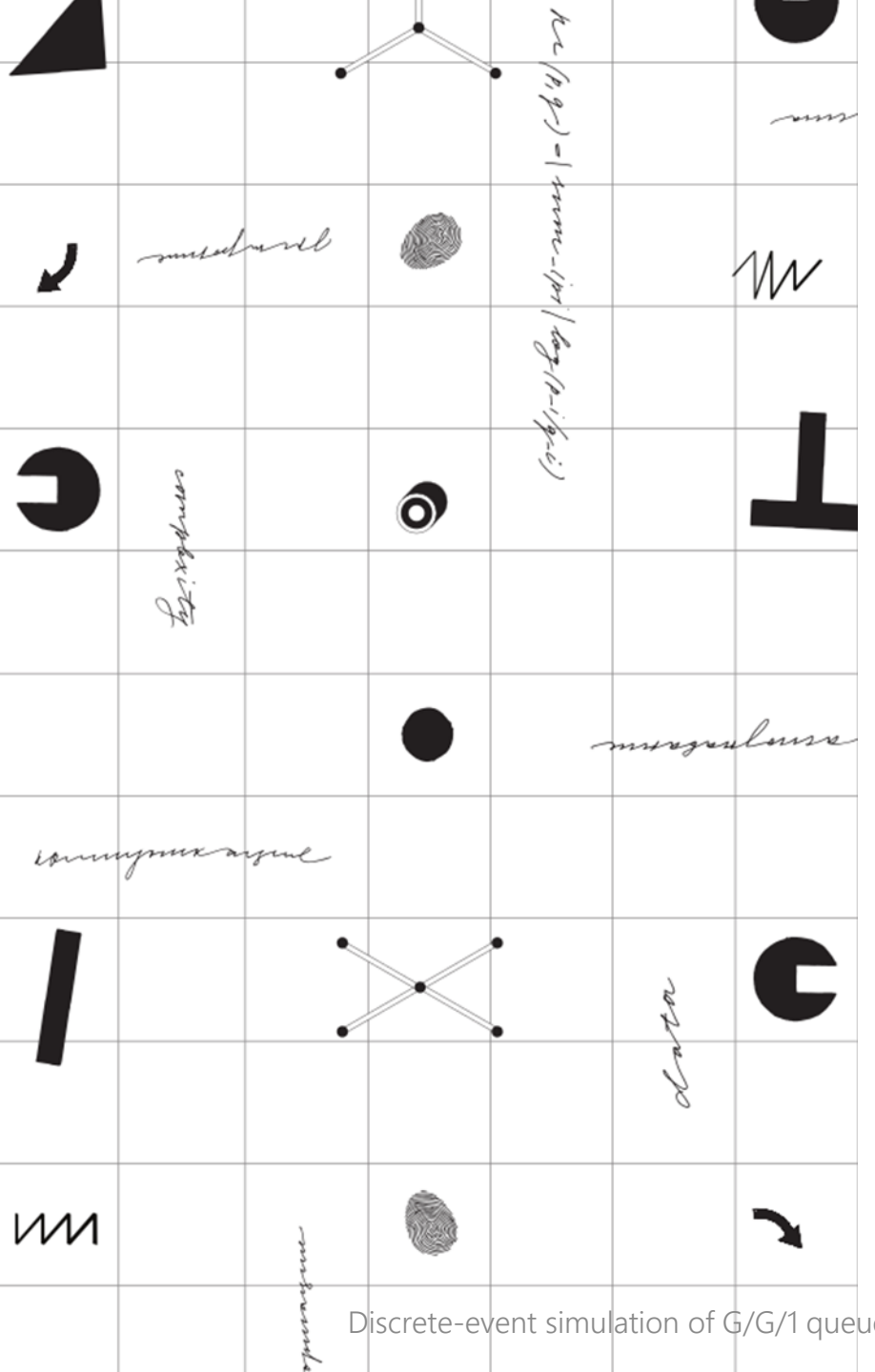
```
int main () {...
  std::shared_ptr<Server> server (new Server ());
  packetGen.SetServer (server);

  Simulator sim;
  sim.SetStop (simTime);
  sim.SetSeed (seed);

  packetGen.Start ();
  sim.Run ();
}
```



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Repo and working with code

Repository

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Address:

sudo apt install git

git clone <address>

Build project

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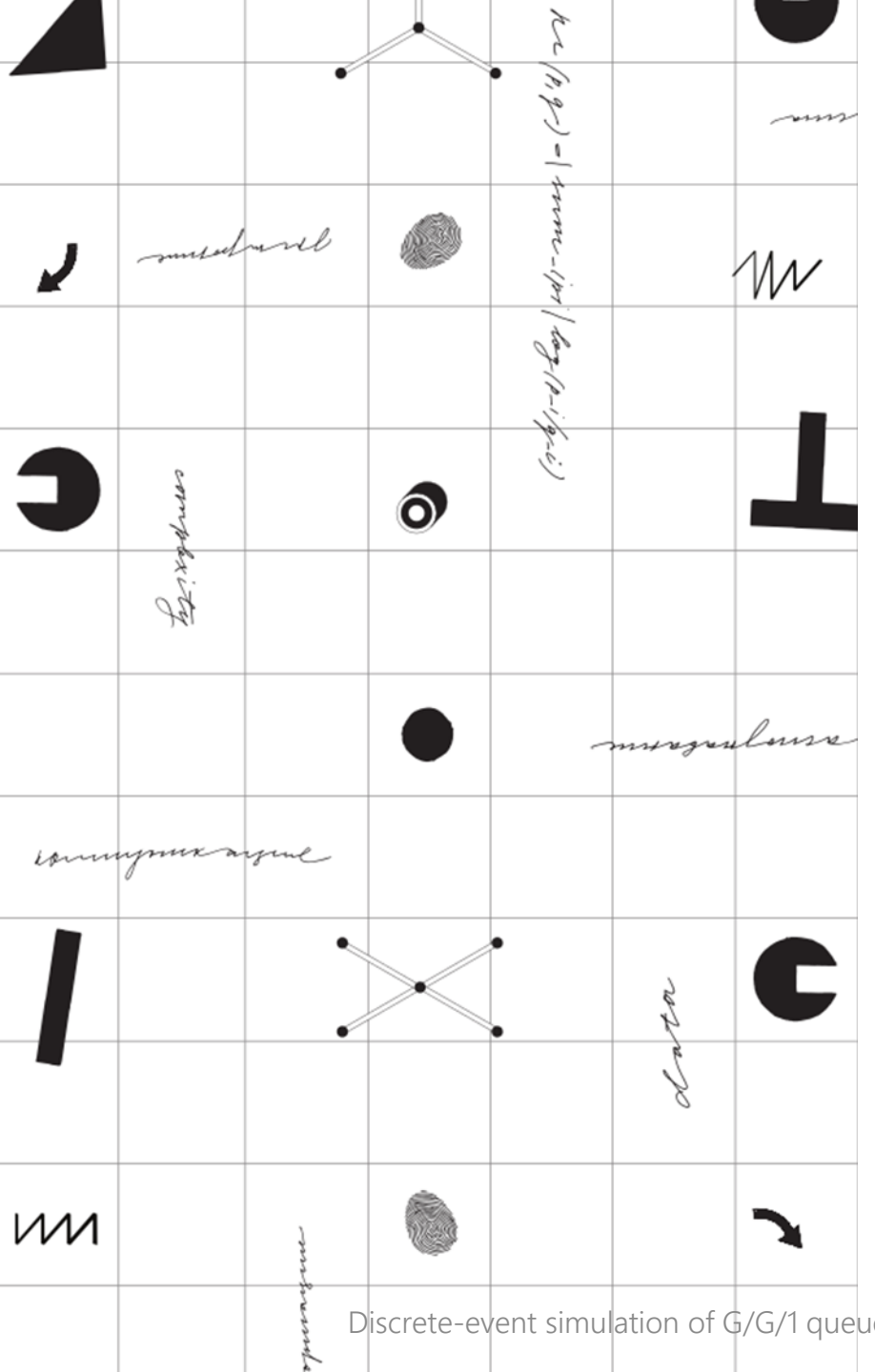
```
CXX=g++
INCLUDES=./
CXXFLAGS=-Wall -O3 -g -std=c++11

scenario : scenario.o server.o queue.o simulator.o packet.o
$(CXX) $(CXXFLAGS) -L$(INCLUDES) -o scenario scenario.o server.o
queue.o simulator.o packet.o

server.o: server.cpp server.h queue.h
$(CXX) $(CXXFLAGS) -L$(INCLUDES) -c server.cpp

clean:
rm -rf *.o scenario
```

GNU Make



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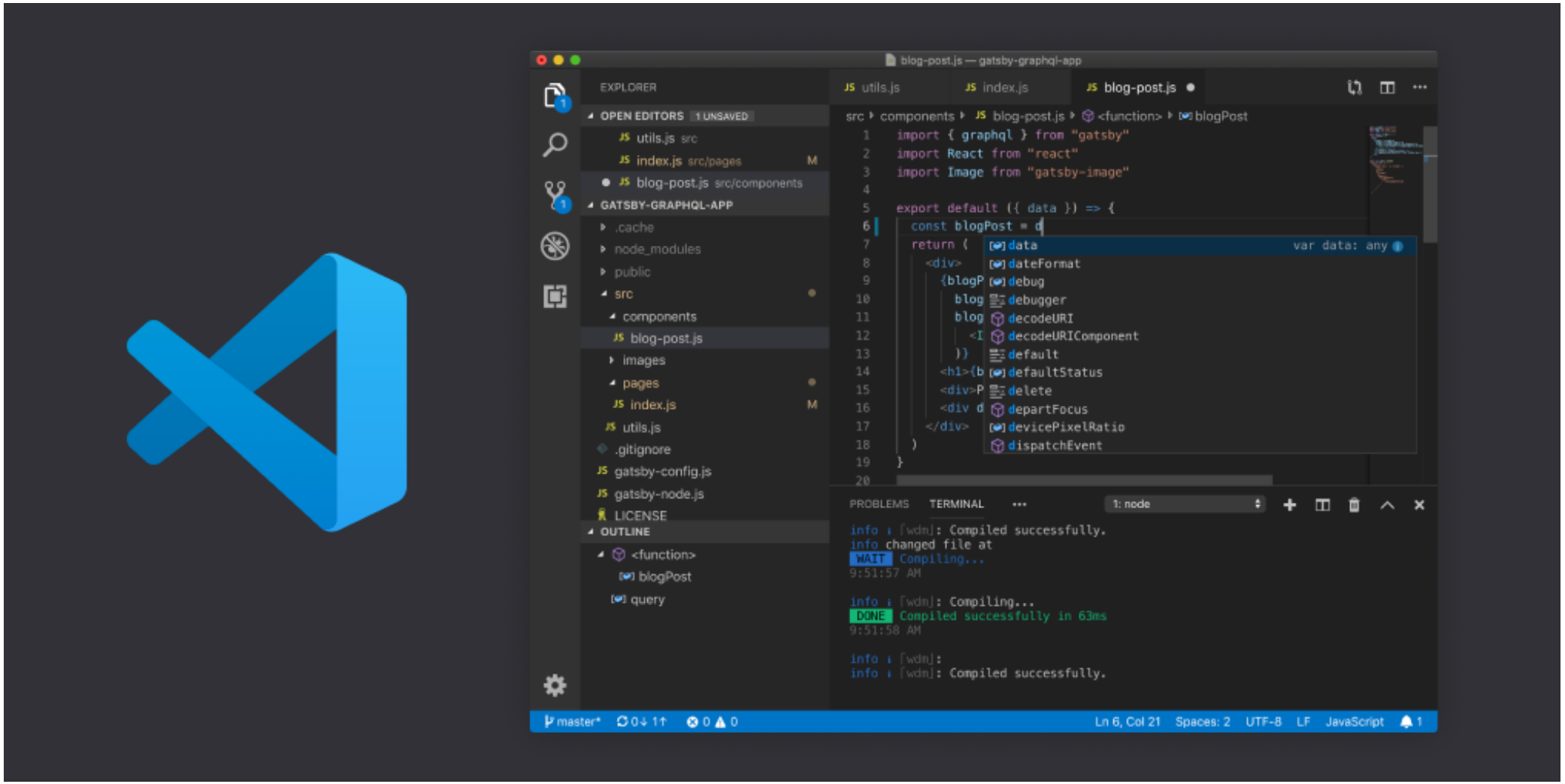
Tools

Visual Studio Code



GNU Parallel

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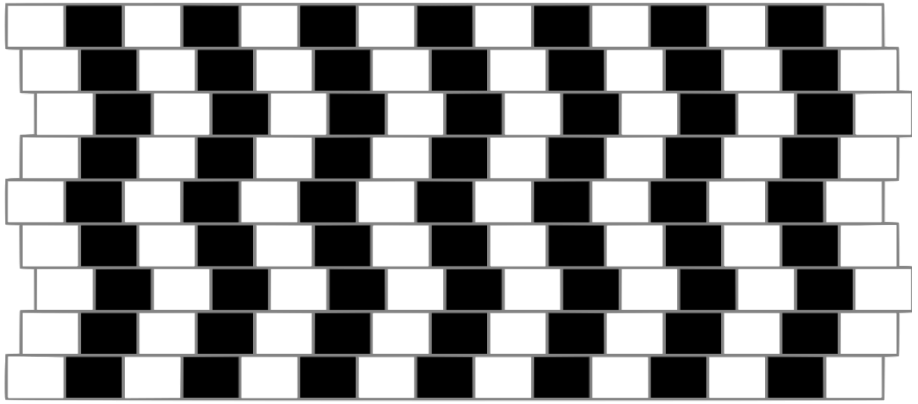
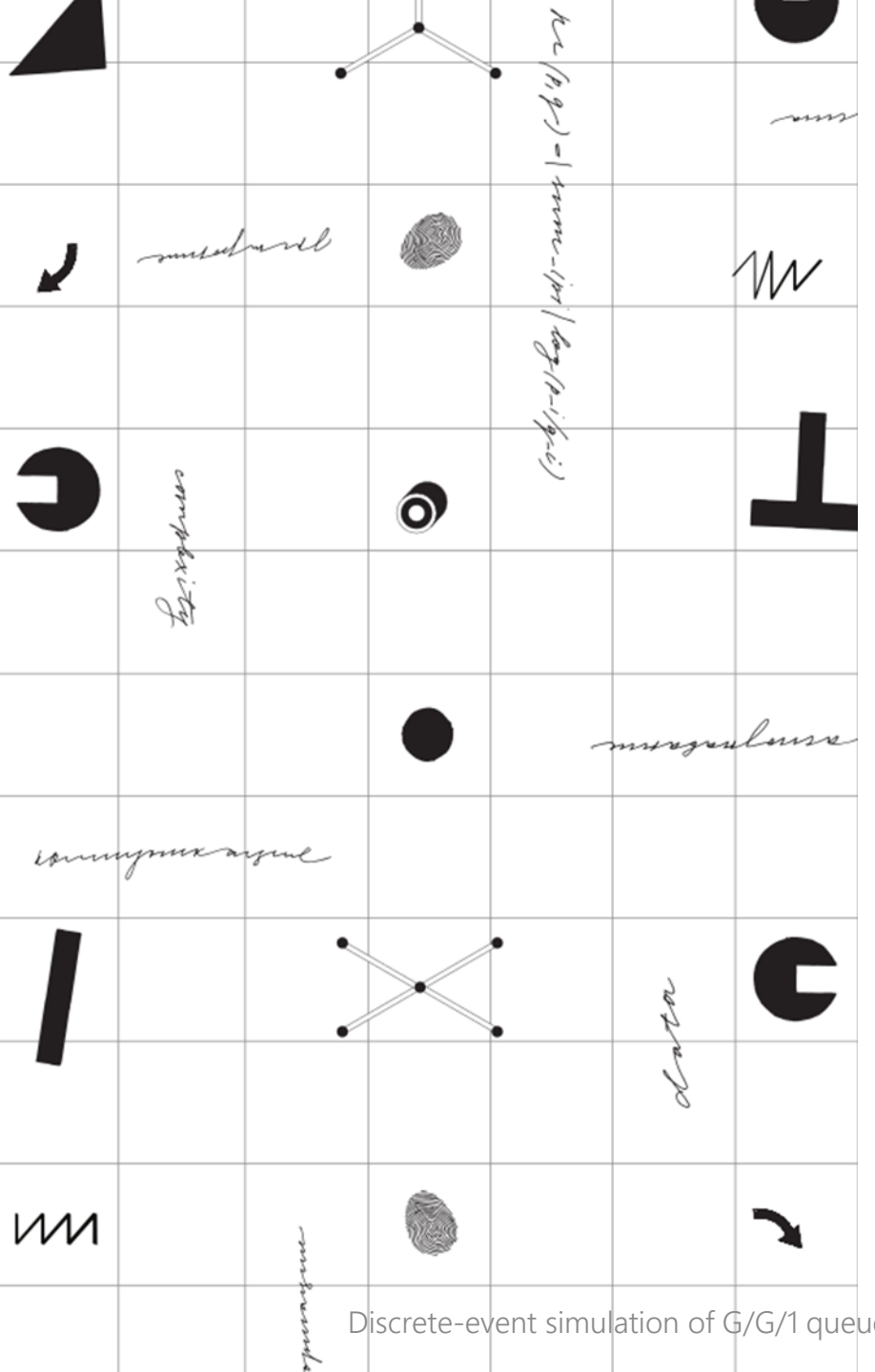
parallel ./scenario {1} {2} {3} ::: $(seq 5) ::: 1 2 3 ::: 4 5 6

To run multiple jobs simultaneously on multiple cores, instead of sequential

./scenario 1 1 4; ./scenario 2 1 4; … ; ./scenario 5 3 6



GNU parallel



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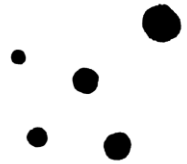
Task

Task description



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1. Run experiment for queueing system M/M/1. Plot figure of mean sojourn time as a function of system load. Compare with analytical estimation.
2. Limit the size of the queue. Plot figures (analytical + simulation) for mean sojourn time and failure probability as functions of system load for different queue sizes.
3. Run experiment for M/D/1 queueing system (service time is constant) with infinite queue. Plot figure of mean sojourn time as a function of system load (analytical + simulation).
4. Prepare a report (problem statement, what you have done, description of results) in LaTeX/Word/etc.

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