Click Coding
Coding with Click Modular Router

Bart Braem — Johan Bergs

University of Antwerp
iMinds - PATS Research Group

Outline

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Do it yourself

Let's make an example element: 1 input, 1 output, Push
Configure a packet size threshold, larger: drop packet
Download the source code online to avoid copy errors at
http://www.pats.ua.ac.be/software/click

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Element header

Necessary in the header:

- Include-guard macros
- Click element macros
- Include click/element.hh
- The class declaration containing 3 special methods:

```
const char *class_name() const
const char *port_count() const
const char *processing() const
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Element header

Necessary in the source file:

- Include click/config.hh **first**!
- CLICK_DECLS macro
- CLICK_ENDDECLS macro
- EXPORT_ELEMENT macro
- Implementations of the methods

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

simplepushelement.hh

```
#ifndef CLICK_SIMPLEPUSHELEMENT_HH
#define CLICK_SIMPLEPUSHELEMENT_HH
#include <click/element.hh>
CLICK_DECLS
class SimplePushElement : public Element {
  public:
    SimplePushElement();
    ~SimplePushElement();
    const char *class_name() const { return "SimplePushElement";}
    const char *port_count() const { return "1/1"; }
    const char *processing() const { return PUSH; }
    int configure(Vector<String>&, ErrorHandler*);
    void push(int, Packet *);
  private:    uint32_t maxSize;
};
CLICK_ENDDECLS
#endif
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

simplepushelement.cc I

```
#include <click/config.h>
#include <click/confparse.hh>
#include <click/error.hh>
#include "simplepushelement.hh"
CLICK_DECLS
SimplePushElement::SimplePushElement(){}
SimplePushElement::~SimplePushElement(){}

int SimplePushElement::configure(Vector<String> &conf, ErrorHandler
    *errh) {
  if (cp_va_kparse(conf, this, errh, "MAXPACKETSIZE", cpkM, cpInteger,
     &maxSize, cpEnd) < 0) return −1;
  if (maxSize <= 0) return errh−>error("maxsize should be larger than 0");
  return 0;
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

simplepushelement.cc II

```
void SimplePushElement::push(int, Packet *p){
  click_chatter("Got a packet of size %d",p->length());
  if (p->length() > maxSize)  p->kill();
  else output(0).push(p);
}
CLICK_ENDDECLS
EXPORT_ELEMENT(SimplePushElement)
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

What's in a name

To avoid confusion, we recommend to:

- Make the ElementName CamelCase
- Use that name in the class_name macro
- Use that name in lowercase for the header (.hh) and source (.cc) files
- Use that name in uppercase, with CLICK_ prepended, for the include guards

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

simplepullelement

```
simplepullelement.hh:
class SimplePullElement: public Element {
  public: ...
    const char *processing() const {return PULL; }
    Packet* pull(int);
}
simplepullelement.cc:
Packet* SimplePullElement::pull(int){
  Packet* p = input(0).pull();
  if(p == 0) return 0;
  click_chatter("Got a packet of size %d",p->length());
  if (p->length() > maxSize){
    p->kill();
    return 0;
  } else return p;
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

simpleagnosticelement

simpleagnosticelement.hh:
```
class SimpleAgnosticElement: public Element {
  public: ...
    const char *processing() const { return AGNOSTIC; }
    void push(int, Packet *);
    Packet* pull(int);
};
```

simpleagnosticelement.cc
```
void SimpleAgnosticElement::push(int, Packet *p){
  // see push element
}
Packet* SimpleAgnosticElement::pull(int){
  // see pull element
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

simpleagnosticelement11

simpleagnosticelement11.hh:
class SimpleAgnosticElement11: **public** Element {
  public: ...
    const char ∗processing() **const** { **return** <u>AGNOSTIC</u>; }
    const char ∗port_count() **const** { **return** "1/1"; }
    Packet ∗<u>simple_action</u>(Packet ∗);
};
simpleagnosticelement11.cc
Packet∗ SimpleAgnosticElement11::<u>simple_action</u>(Packet ∗p){
  click_chatter("Got a packet of size %d",p−>length());
  if (p−>length() > maxSize){
    p−>kill();
    return 0;
  } **else return** p;
}

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Port count

Defined by const char *port_count() const can return:

- "1/1": one input port, one output port
- "1/2": one input port, two output ports
- "1-2/0": one or two input ports and zero output ports.
- "1/-6": One input port and up to six output ports.
- "2-/-": At least two input ports, any number of output ports.
- "3": Exactly three input and output ports. (If no slash appears, the text is used for both input and output ranges.)
- "1-/=": At least one input port and the same number of output ports.
- "1-/=+": At least one input port and one more output port than there are input ports.

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Parsing configurations with cp_va_kparse I

Call this function on

- the configuration (conf)
- the element (this)
- the errorhandler (errh)
- an argument list
- a closing mark (cpEnd)

Check the return value (C-style):

- 0: all parsing went fine
- Negative: problems detected, configure should return -1

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Parsing configurations with cp_va_kparse II

```
int MyElement::configure(Vector<String> &conf, ErrorHandler *errh) {
  String data;
  uint32_t limit = 0;
  bool stop = false;
  if (cp_va_kparse(conf, this, errh,
    "DATA", cpkP+cpkM, cpString, &data,
    "LIMIT", cpkP, cpUnsigned, &limit,
    "STOP", 0, cpBool, &stop,
    cpEnd) < 0) return −1;
  ...
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Arguments to cp_va_kparse I

Argument name

- Type: const char *
- Example: "DATA".

Parse flags

- Type: int
- Zero or sum of cpkP, cpkM, and cpkC.

If the parse flags contain cpkC, then a confirmation flag comes next:

- Type: bool *
- This flag is set to true if an argument successfully matched the item and false if not.

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Arguments to cp_va_kparse II

Argument type: Defines the type of argument read from the configuration string

- Type: CpVaParseCmd
- Example: cpString, cpIPAddress, cpInteger

Optional parse parameters

- Determined by the argument type
- For example, cpUnsignedReal2 takes a parse parameter that defines how many bits of fraction are needed.

Result storage: Determined by the argument type

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Parse flags

- cpkN (=0): default, no special requirements
- cpkM: Mandatory argument
- cpkP: Positionally specified argument
- cpkC: Confirmation of presence needed
- cpkD: Deprecated argument

To combine just sum them, e.g. cpkD+cpkC: deprecated argument that will be confirmed

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Cp_va_kparse: example

```
int MyElement2::configure(Vector<String> &conf,
    ErrorHandler *errh) {
  bool p_given;
  uint32_t p = 0x10000;
  IPAddress addr, mask;
  if (cp_va_kparse(conf, this, errh,
    "P", cpkC, &p_given, cpUnsignedReal2, 16, &p,
    "NETWORK", 0, cpIPPrefix, &addr, &mask,
    cpEnd) < 0)
  return -1;
  ...
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Cp_va_kparse: example 2 I

```
cp_va_kparse(conf, this, errh, "P", cpkC, &p_given,
    cpUnsigned, &p, "NETWORK", 0, cpIPAddress, &addr,
    &mask, cpEnd)
```

Will this match:

- P 5, NETWORK 192.168.0.3
- NETWORK 1.2.3.4, P5
- P 5
- NETWORK 192.168.0.3
- (nothing)

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Cp_va_kparse: example 2 II

How about

```
cp_va_kparse(conf, this, errh, "P", cpkC, &p_given,
    cpUnsigned, &p, "NETWORK", cpkM, cpIPAddress,
    &addr, &mask, cpEnd)
```

Will this match:

- P 5, NETWORK 192.168.0.3
- NETWORK 1.2.3.4, P5
- P 5
- NETWORK 192.168.0.3
- (nothing)

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Parsing elements I

Elements might need other elements

- Pass them in the configuration
- Check their name and type
- Calling public methods and accessing public members is possible

In Click script:

```
SimpleElement(IPRouteTable);
```

or

```
myIpRouteTable::IPRouteTable;
SimpleElement(myIpRouteTable);
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Parsing elements II

Add an element to the header:

```
#include "usedelement.hh"
class ElementUser: public Element{
 private:
    UsedElement* used;
}
```

Use the element in the C++ code

```
ElementUser::push(...){
  used->doSomething(...);
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Parsing elements III

Check and configure the element in the configure function:

```
int ElementUser::configure(Vector<String> &conf,
    ErrorHandler *errh){
  UsedElement* tempUsedElement;
  int res = cp_va_kparse(conf, this, errh,
    "ANELEMENT", 0, cpElementCast, "UsedElement",
    &tempUsedElement, cpEnd);
  if(res < 0) return res; // parsing failed
  used = tempUsedElement;
  return 0;
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click library functions

The C++ STL cannot be used in the kernel

- Click provides its own implementation, use it
- Equivalents to most STL datastructures available
- E.g. vector, hashmap, ...

Additional types: Timers and tasks to schedule actions, see later
Additional functions:

- Manipulate strings
- Manipulate packets
- E.g. `click_gettimeofday(struct timeval *tv)`

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click containers

Overview of the most important types

- Vector
- HashMap (will become HashContainer)
- String

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click STL: vector I

Constructor: straightforward template

Vector<SomeThing> myvector;

Even better: typedef it for reuse

Typedef Vector<SomeThing> SomeThingVector;

Use macro magic for template instantiation

```
// generate Vector template instance
#include <click/vector.cc>
#if EXPLICIT_TEMPLATE_INSTANCES
template class Vector<SomeThing>;
#endif
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click STL: vector II

Add things to it: `myvector.push_back(some_thing);`

Use iterators to walk over it

```
for (SomeThingVector::const_iterator i =
    myvector.begin(); i!= myvector.end(); i++){
  doSomeThingWith(*i);
}
```

And remove things with iterators

`myyvector.erase(i);`

Or pop it as a stack/heap

`myvector.pop_front(); myvector.pop_back();`

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click STL: hashmap example I

```cpp
#ifndef AODVSETRREPHEADERS_HH
#define AODVSETRREPHEADERS_HH
#include <click/element.hh>
CLICK_DECLS
typedef HashMap<Packet*, IPAddress*> DestinationMap;
class AODVSetRREPHeaders : public Element {
  public:
    virtual void push (int, Packet *);
    void addRREP(Packet*,IPAddress *);
  private:
    DestinationMap destinations;
};
CLICK_ENDDECLS
#endif
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click STL: hashmap example II

```
AODVSetRREPHeaders::AODVSetRREPHeaders():
  destinations(){}
void AODVSetRREPHeaders::push (int port, Packet * p){
  ...
  // packet should be in destinations
  DestinationMap::Pair * pair = destinations.find_pair(packet);
  assert(pair);
  IPAddress* destination = pair->value;
  ... // do something with destination
  delete pair->value; // free memory properly
  destinations.remove(packet); // then remove from map
  ...
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click STL: hashmap example III

```
void AODVSetRREPHeaders::addRREP(Packet* rrep, IPAddress * ip){
  destinations.insert(rrep,ip);
}
// macro magic to use bighashmap
#include <click/bighashmap.cc>
#if EXPLICIT_TEMPLATE_INSTANCES
template class HashMap<Packet*, IPAddress*>;
#endif
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click STL: string

Use it when manipulating C strings

String test = "mytest";

Use standard operators to modify it

test += "should say hello";

When used in click_chatter, convert it

click_chatter("my string is %s",test.c_str());

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Packet formats

You want to make your own packets, here's how

Format closely mirrors RFCs

Use structs

- Fill them with signed/unsigned ints, in_addr, ...
- Easy packet manipulation
- Avoids dirty operations with chars and bytes
- Define those in shared headers for reuse

Create your packet format

```
struct MyPacketFormat{
  uint8_t type; // 8 bit = 1 byte
  uint32_t lifetime; // 32 bit = 4 bytes
  in_addr destination; // IP address
};
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Click data types

Click already defines lots of data types for you, see
`include/clicknet`:

- `click_ether`
- `click_ip`
- `click_udp`
- `click_tcp`
- etc.

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Creating a packet

Provide headroom and tailroom:

```
int tailroom = 0;
int packetsize = sizeof(MyPacketFormat);
int headroom = sizeof(click_ip)+sizeof(click_udp)+sizeof(click_ether);
WritablePacket *packet = Packet::make(headroom,0,packetsize, tailroom);
if (packet == 0 )return click_chatter( "cannot make packet!");
memset(packet−>data(), 0, packet−>length());
MyPacketFormat* format=(MyPacketFormat*)packet−>data();
format−>type = 0;
format−>lifetime = htonl(counter);
format−>destination = ip.in_addr();
```

Destroy with `packet->kill()`, only way to free your memory correctly!

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Processing a packet I

Cast the packet data to the right format

```
// start with the first part
my_header * head = (my_header *) (packet−>data());
// continue with later bytes
int offset = sizeof(my_header)
second_header * h2 = (my_second_header *)(my_header+1);
```

Use the format to read from and write to

```
if (head−>somefield == 2){
  head−>otherfield = htons(38);
  ...
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Processing a packet II

Only write to writable packets

```
WritablePacket *q = p->uniqueify();
// only use q now!
q->somefield = newvalue
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Manipulating packet size

Add data with push(unsigned len)

- Inserts the data at the beginning of the packet
- Create enough headroom, otherwise expensive push!

Remove data with pull(unsigned len)

- Removes the data at the beginning of the packet
- Frees headroom

Equivalents at tail of packet: put and take

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Manipulating packet annotations

Get IP header:

packet−>ip_header();

Set IP header of length len:

packet−>set_ip_header(**const** click_ip∗ header, **unsigned** len);

Similar operations exist for TCP and UDP headers
Both operations require header annotations, set by the
MarkIPHeader element!

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Simple timer I

Runs the run_timer function upon expiry

```
class MyElement: public Element {
  public:
    void run_timer(Timer*);
  private:
    Timer timer;
}
MyElement::MyElement(): timer(this){}
int MyElement::configure(Vector<String> &conf, ErrorHandler *errh){
  timer.initialize(this);
  timer.schedule_after_msec(1000);
  return 0;
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Simple timer II

```
void MyElement::run_timer(Timer* t){
  click_chatter("we are now 1 second later");
  timer.schedule_after_msec(1000);
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Advanced timer with extra data I

Run your callback function upon expiry with data, because you want to know some context information.
Code is a little bit harder:

```
class MyElement: public Element{
  private:
    struct TimerData{ // callback data
      MyElement* me;
      Something* s;
    }
  static void handleExpiry(Timer*, void *); // callback function
  void expire(const MyElement &, TimerData *);
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Advanced timer with extra data II

```
void MyElement::someFunction(){
  TimerData∗ timerdata = new TimerData();
  timerdata−>s = new Something();
  timerdata−>me = this;
  Timer t = new Timer(&MyElement::handleExpiry,timerdata);
  t−>initialize(this);
  t−>schedule_after_msec(2500);
}
void MyElement::handleExpiry(Timer∗, void ∗ data){
  TimerData ∗ timerdata = (TimerData∗) data;
  assert(timerdata); // the cast must be good
  timerdata−>me−>expire(∗timerdata−>s,timerdata);
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Advanced timer with extra data III

```
void MyElement::expire(const Something & s, TimerData ∗ timerdata){
  // do things with Something
  // timerdata passed to free memory after timer expiry
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Adding handlers

Add to element by overriding `add_handlers`

- Callback with function pointers
- Refer to static methods

Use `add_read_handler` and `add_write_handler`

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Adding a write handler I

```
class WriteElement: public Element{
  public:
    static int handle(const String &conf, Element *e, void * thunk,
      ErrorHandler * errh);
    void add_handlers();
}

int WriteElement::handle(const String &conf, Element *e, void * thunk,
    ErrorHandler * errh){
  WriteElement * me = (WriteElement *) e;
  if(cp_va_kparse(conf, me, errh, ..., cpEnd) < 0) return −1;
  me−>doSomethingWithParsed(...);
  return 0;
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Adding a write handler II

```
void WriteElement::add_handlers(){
  add_write_handler("a_handle", &handle, (void *)0);
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

Adding a read handler

```
class ReadElement: public Element{
  public:
    static String handle(Element *e, void * thunk);
    void add_handlers();
}

String ReadElement::handle(Element *e, void * thunk){
  ReadElement * me = (ReadElement *) e;
  return me->giveSomeValue(...);
}
void ReadElement::add_handlers(){
  add_read_handler("a_handle", &handle, (void *)0);
}
```

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

References I

Click website: http://www.read.cs.ucla.edu/click/

- Element documentation (by name or category)
- Programming Concepts
- Doxygen documentation

Click thesis (online: publications, Ph.D. thesis)

- Comprehensive documentation of every concept
- Interesting chapters for development:
  - Introduction
  - Architecture: elements, packets, connections, push and pull, packet storage, element implementation
  - Language: syntax, configuration strings, compound elements

Click source code

Outline
Coding
Tools

Writing custom elements
The Click STL
Packet Manipulation
Timers and Tasks
Handlers
References

References II

- /elements/: dozens of elements, some more trivial than others
- /include/: the Click STL headers

Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

Introduction

Click graphs can get large, sometimes you need visual checks
Helps you verify the situation
Tools available:

- click-flatten
- click-viz

Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

click-flatten

Flattens out compound elements for click-viz, the resulting router
will do exactly the same
Located in tools/click-flatten

Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

click-flatten (continued)

```
tools/click−flatten/click−flatten ping−3.click
# 33 "ping−3.click"
AddressInfo@1 :: AddressInfo(senderaddr 10.0.0.1 1A:7C:3E:90:78:41);
# 34 "ping−3.click"
AddressInfo@2 :: AddressInfo(receiveraddr 10.0.0.2 1A:7C:3E:90:78:42);
# 40 "ping−3.click"
Null@5 :: Null;
# 43 "ping−3.click"
Null@6 :: Null;
# 4 "ping−3.click"
sender/ICMPPingSource@1 :: ICMPPingSource(senderaddr, receiveraddr);
...
```

Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

click-flatten (continued)

```
sender/ICMPPingSource@1 -> sender/IPPrint@2
  -> sender/EtherEncap@3
  -> sender/ToDump@4
  -> Null@5
  -> receiver/Strip@1
  -> receiver/MarkIPHeader@2
...
  -> sender/IPPrint@6
  -> sender/Discard@7;
sender/filter [1] -> sender/IPPrint@8
  -> sender/Discard@9;
```
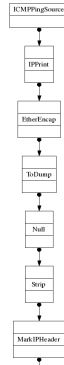
Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

click-viz

Basic visualization of Click scripts, renders dotty output (Graphviz software)
Usage:

tools/click−flatten/click−flatten ping−1.click |
    tools/click−viz/click−viz | dot −Tpng >
    ping−1.png

Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

Gnu Debugger

A low-level, well known and very powerful debugger
Basics:

- gdb userlevel/click
- run someclickscript.click
- (wait for crash)
- bt
- quit

Outline
Coding
Tools

Introduction
click-flatten
click-viz
gdb
valgrind

valgrind

A memory debugger, shows and debugs invalid memory access
Basic usage: `valgrind userlevel/click somescript.click`
Errors and warnings might come from glibc or Click elements, and
might appear in other elements.