Click Coding

Coding with Click Modular Router

Bart Braem Johan Bergs

University of Antwerp
iMinds - MOSAIC Research Group

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Outline

Do it yourself

Let's make an example element

- 1 input, 1 output, Push
- Configure a packet size threshold, if larger: drop packet

Download the source code online to avoid copy errors at
`https://github.com/mosaicresearch/click_modular_router_lessons/tree/master/examples/simpleelements`

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**

Element header

Necessary in the source file:

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

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
```

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;
}

void SimplePushElement::push(int, Packet *p){
```

simplepushelement.cc II

```
  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)
```

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

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;
}
```

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
}
```

simpleagnosticelement11

simpleagnosticelement11.hh:

```
class SimpleAgnosticElement11: public Element {
  public: ...
    const char *processing() const { return AGNOSTIC; }
    const char *port_count() const { return "1/1"; }
    Packet *simple_action(Packet *);
};
```

simpleagnosticelement11.cc

```
Packet* SimpleAgnosticElement11::simple_action(Packet *p){
  click_chatter("Got a packet of size %d",p->length());
  if (p->length() > maxSize){
    p->kill();
    return 0;
  } else return p;
}
```

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.

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

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;
  ...
}
```

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.

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

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

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;
  ...
}
```

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)

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)

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);
```

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(...);
}
```

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;
}
```

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)

Click containers

Overview of the most important types

- Vector
- HashMap (will become HashContainer)
- String

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
```

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();

Click STL: hashmap example I

```
#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
```

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
  ...
}
```

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
```

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());

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
};
```

Click data types

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

- click_ether
- click_ip
- click_udp
- click_tcp
- etc.

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!

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);
  ...
}
```

Processing a packet II

Only write to writable packets

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

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

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!

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;
}
```

Simple timer II

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

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 *);
}
```

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);
}
```

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
}
```

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

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;
}
```

Adding a write handler II

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

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);
}
```

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

References II

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

Introduction

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

- click-flatten
- click-viz

click-flatten

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

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);
...
```

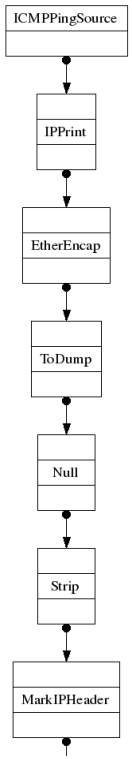
click-flatten (continued)

```
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;
```

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
```



Gnu Debugger

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

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

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.

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