

# Click Coding

## Coding with Click Modular Router

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# Outline

1 Coding

2 Tools



# 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>



# 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
- Implementations 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, cplInteger,
        &maxSize, cpEnd) < 0) return -1;
    if (maxSize <= 0) return errh->error("maxsize should be larger than 0");
    return 0;
}
```



## 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)
```





# 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;
```

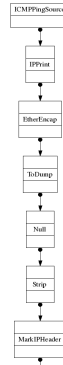


# click-viz

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.

