Object Oriented Software Design II

Real Application Design

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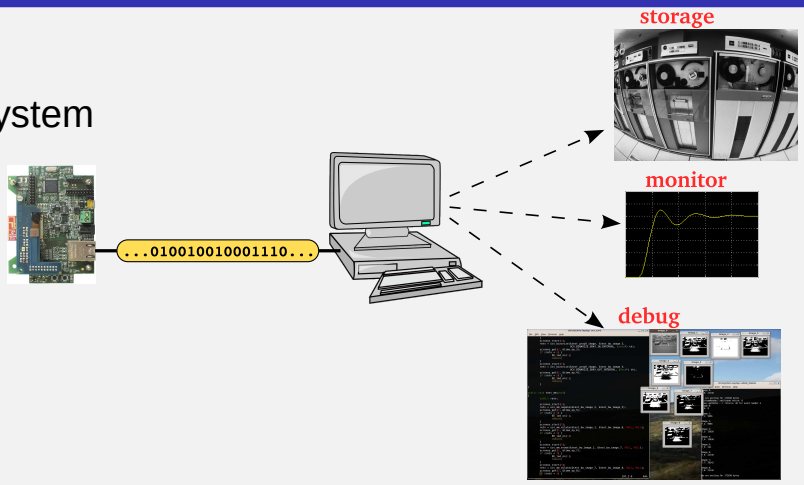
Outline

Data AcQuisition System

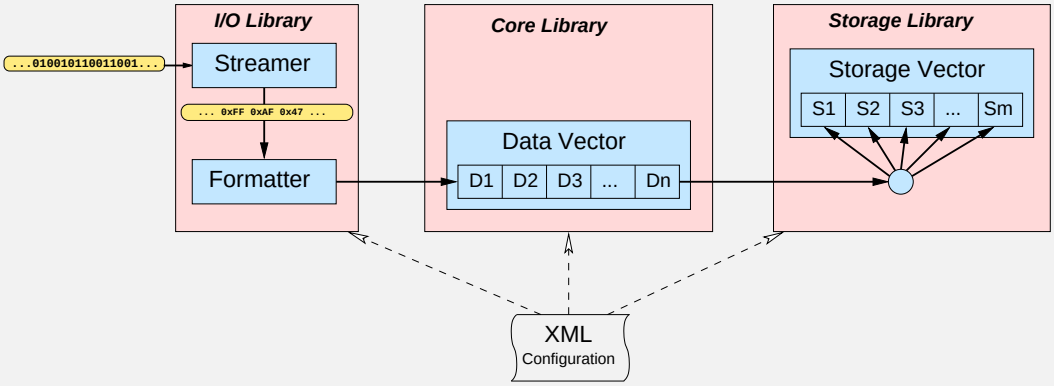
A basic DAQ system



duck-lab: an open-source DAQ framework

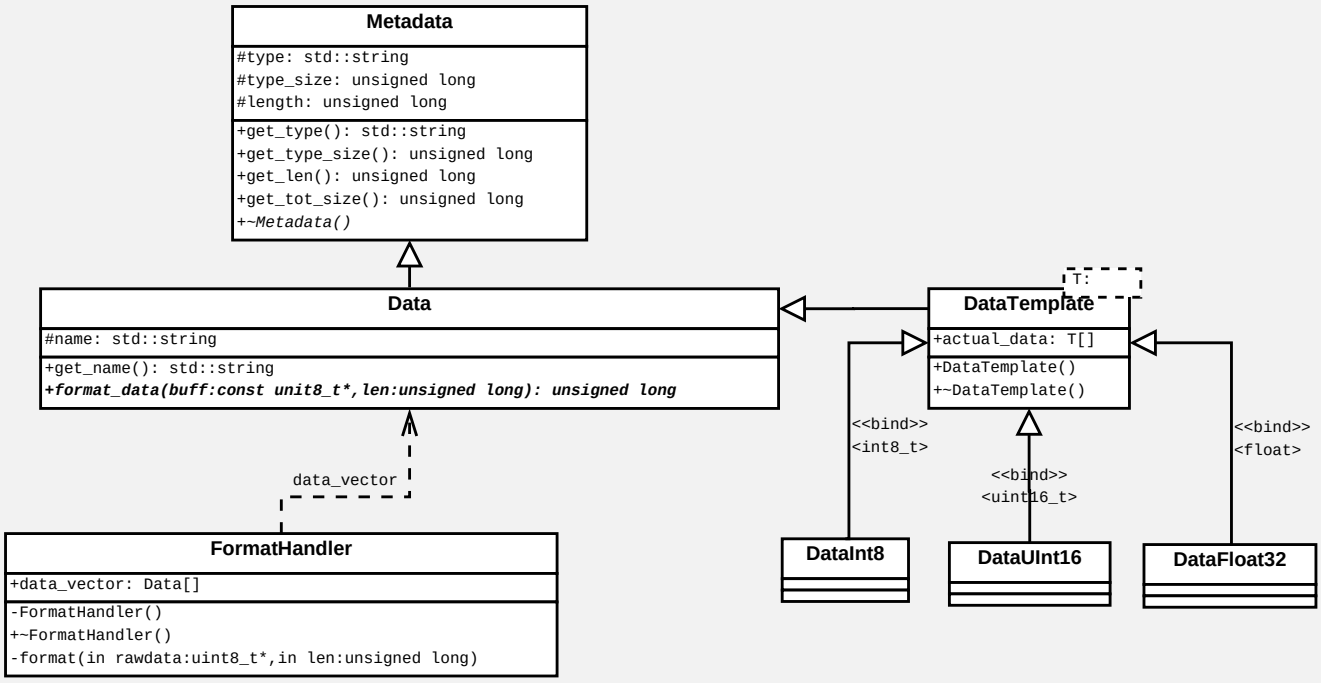
- Project (temporary) home page: `http://retis.sssup.it/~chris/duck-lab`
- Mercurial revision control: `https://rtn.sssup.it/hg/duck-lab` (`hg clone https://rtn.sssup.it/hg/duck-lab`)

duck-lab architecture



- We have defined a hierarchy for `Data`
- We have defined the interaction with the Formatter, implemented by the `FormatHandler` class

duck-lab architecture



The `FormatHandler` class

- We have done `Data` creation/destruction
- We have done `Data` formatting

```
class FormatHandler {
public:
    FormatHandler();
    ~FormatHandler();
    void format(const uint8_t* rawdata,
                unsigned long len);
private:
    std::vector<Data*> data_vector;
};
```

Factory Method Pattern with `string`-based look-up table (`std::map`) (almost good)

Polymorphic destruction (good!)

Polymorphic formatting with delegation to the `Data` classes (good!)

- So, given the following configuration (XML)

```
<message_description>
   <data data_type="uint16"  data_name="data_name_1" data_len="2"/>
   <data data_type="float32" data_name="data_name_2" data_len="1"/>
   <data data_type="int8"    data_name="data_name_3" data_len="4"/>
</message_description>
```

FormatHandler ctor and dtor

DataExample5-to-exercise-solution/FormatHandler.cc

```
FormatHandler::FormatHandler()
{
        // We create the data vector according to XML config
        vector<XmlDataElement> config = parse_xml_data();

        vector<XmlDataElement>::const_iterator it;
        for (it = config.begin(); it != config.end(); ++it) {
                Data *d = DataFactory::create(it->type, it->name, it->len);
                if (!d) {
                        cout << "Unable to create data type = '" << it->type <<
                                "' ! Skipping" << endl;
                        continue;
                }
                data_vector.push_back(d);
        }
}
```

DataExample5-to-exercise-solution/FormatHandler.cc

```
FormatHandler::~FormatHandler()
{
        // We have to destroy the data vector properly
        vector<Data*>::iterator it;
        for (it = data_vector.begin(); it != data_vector.end(); ++it)
                delete *it;
}
```


DataFactory

Has anybody finished, if started, doing last exercise?

DataExample5-to-exercise-solution/DataFactory.h

```
class DataFactory {
public:
        typedef Data* (*creator_type_t)(const std::string&, unsigned long);

        static Data* create(const std::string& id, const std::string& name,
                            unsigned long len);
private:
        static std::map<std::string, creator_type_t> lookup_table;
};
```

DataExample5-to-exercise-solution/DataFactory.cc

```
std::map<string, DataFactory::creator_type_t> DataFactory::lookup_table;

Data* DataFactory::create(const string& id, const string& n, unsigned long len)
{
        if (lookup_table.empty()) {
                lookup_table["int8"] = DataInt8::create;
                lookup_table["uint16"] = DataUInt16::create;
                lookup_table["float32"] = DataFloat32::create;
        }
        map<string, creator_type_t>::iterator elem = lookup_table.find(id);
        if (elem == lookup_table.end()) {
                cout << "Fatory Creation Error: Creator not registered"
                        " for ID=" << id << endl;
                return NULL;
        }
        return elem->second(n, len);
}
```

Definitions

Static storage duration

- Variables shall last for the entire duration of the program
- Variables with constructor/destructor having side effects cannot be eliminated

Non-local variables

- Typically known as “global” variables
- Either with *static storage duration*...
- or *thread storage duration* (defined in C++11)

“Non-local variables with static storage duration are initialized as a consequence of program initiation.”

[C++11 standard: n3242, sec 3.6.2]

Variables with static storage duration

Three possible cases:

Non-local variables

```
int var1;
static float var2;

int main(void) { return 0; }
```

Static as linkage rule

Local variables

```
void f(void)
{
    static int var = 123;
    //...
}
```

Declaration of static durarion

Static class data member (treated as non-local variable)

```
class Test {
//...
    static int var;
};

int Test::var;
```

Declare static class member

Necessary to define (allocate) data member

Notice the different usages of `static`

Initialization Type

Two possible initializations

- *static initialization*

  zero initialization

```
int var;
int* ptr;
int array[3];
float real;
int main(void) {return 0;}
```

  constant initialization

```
int var = 123;
int* ptr = &var1;
int array[3] = {1, 2, 3};
int main(void) {return 0;}
```

- *dynamic initialization*: all other initializations

```
inline int f() {return 123;}
int var = f();
float real = 3.14; // Dynamic Initilization!
int main(void) {return 0;}
```


Initialization: Static vs Dynamic

Considering non-local variable with static storage duration

Static initialization

- Initialization value computed at compile time
- All static initializations occur before any dynamic initialization

Dynamic initialization

- Initialization value computed at runtime
- Under certain circumstances static initialization **might** be used in place of dynamic one
- Initialization **might** occur before first statement of `main`, otherwise...
  - *"it shall occur before the first odr-use of any function or variable defined in the same translation unit as the variable to be initialized."* *[C++11 standard: n3242, sec 3.6.2, par 4]*
  - *"A non-local variable with static storage duration having initialization with side-effects must be initialized even if it is not odr-used"* *[C++11 standard: n3242, sec 3.6.2, note 34]*

Note:

- Variables might be static- (zero-) initialized first and dynamic-initialized later.
- User-defined types variable (classes) are subject to static and dynamic initialization too.

User-defined type: static initialization

“if T is a (possibly cv-qualified) non-union class type, each non-static data member and each base-class subobject is zero-initialized and padding is initialized to zero bits”

[C++11 standard: n3242, sec 8.5, par 5]

```
struct Simple {
    int var;
    int* ptr;
    char str[10];
};

Simple s;

int main(void)
{
    cout << "Simple has: " << s.var << " " <<
         s.ptr << " ’" << s.str << "’" << endl;
    return 0;
}
```

```
Simple has: 0 0 ’’
```


User-defined type: dynamic initialization

When zero-initializtion constuction is not sufficient...

```
struct Simple {
    int var;
    int* ptr;
    char str[10];
    Simple() : var(123), ptr(&var)
    {
        strcpy(str, "Hello");
    }
};

Simple s;

int main(void)
{
    cout << "Simple has: " << s.var << " " <<
         s.ptr << " ’" << s.str << "’" << endl;
    return 0;
}
```

User-provided constructor

Requesting a **run-time** call to the user-provided constructor

```
Simple has: 123 0x6013a0 ’Hello’
```

And now?

- The question is: why do we care about all this stuff?
- It turns out that non-local variable initialization can be exploited to execute code “at start-up”.

> Dynamic initialization **might** occur before first statement of `main`, otherwise...
>
> - *“it shall occur before the first odr-use of any function or variable defined in the same translation unit as the variable to be initialized.”*
> - *“A non-local variable with static storage duration having initialization with side-effects must be initialized even if it is not odr-used”*

Suppose to have:

- a non-local variable of user-defined type (class)
- which a user-provided constructor
- which has side-effects (produces changes in the execution environment)

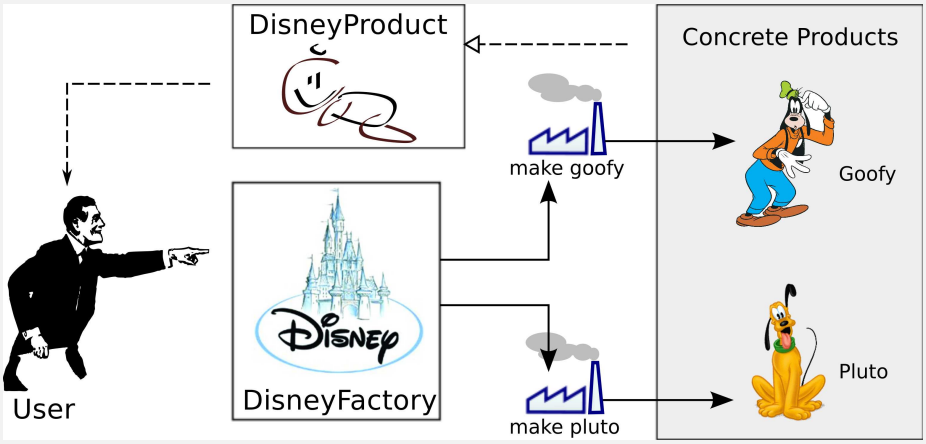
Example

```
struct MyClass {
    MyClass()
    {
        cout << "Make world..." << endl;
        // ...
    }
    //...
};

MyClass c;

int main(void)
{
    cout << "Hello world!" << endl;
    return 0;
}
```

```
Make world...
Hello world!
```

The Disney's cartoons problem

- The *user* wants to animate cartoons
- The *user* does not care about their creation process



C++ implementation

FactoryExample4.h

```
class DisneyProduct {
public:
        virtual ~DisneyProduct() {};
        inline std::string get_name(void) const { return name; };
protected:
        DisneyProduct(const std::string& n) : name(n) {};
private:
        DisneyProduct(const DisneyProduct&);
        DisneyProduct &operator=(const DisneyProduct&);
        std::string name;
};
```

FactoryExample4.h

```
class Goofy : public DisneyProduct {
private:
        Goofy() : DisneyProduct("goofy") {};
        static DisneyProduct* create(void) { return new Goofy(); };
        friend class DisneyFactory;
};

class Pluto : public DisneyProduct {
private:
        Pluto() : DisneyProduct("pluto") {};
        static DisneyProduct* create(void) { return new Pluto(); };
        friend class DisneyFactory;
};
```

C++ implementation

FactoryExample4.h

```
class DisneyUser {
public:
        DisneyUser();
        ~DisneyUser();
        void animate(void);
private:
        std::vector<DisneyProduct*> toons;
};
```


C++ implementation

FactoryExample4.cc

```
DisneyUser::DisneyUser()
{
        const char* config[] = {"goofy", "pluto", "pluto", "invalid_id"};

        for (size_t i = 0; i < 4; i++) {
                DisneyProduct *p = DisneyFactory::create(config[i]);
                if (p)
                        toons.push_back(p);
        }
}

DisneyUser::~DisneyUser()
{
        vector<DisneyProduct*>::iterator it;
        for (it = toons.begin(); it != toons.end(); ++it)
                delete *it;
}

void DisneyUser::animate(void)
{
        vector<DisneyProduct*>::const_iterator it;
        for (it = toons.begin(); it != toons.end(); ++it)
                cout << "Hullo, my name is " << (*it)->get_name() << endl;
}
```

C++ implementation

FactoryExample4.h

```
class DisneyFactory {
public:
        static DisneyProduct* create(const std::string& id);
private:
        typedef DisneyProduct* (*creator_type_t)(void);
        static std::map<std::string, creator_type_t> lookup_table;
};
```

FactoryExample4.cc

```
map<std::string, DisneyFactory::creator_type_t> DisneyFactory::lookup_table;

DisneyProduct* DisneyFactory::create(const string& id)
{
        if (lookup_table.empty()) {
                lookup_table["goofy"] = Goofy::create;
                lookup_table["pluto"] = Pluto::create;
        }
        if (lookup_table.find(id) == lookup_table.end())
                return NULL;
        return lookup_table[id]();
}
```


Consideration

- What about *extensibility*?
- Adding new `DisneyProduct` requires the following modifications:
  1. definition of the new `DisneyProduct` (e.g. `DonalDuck`)
  2. adding a new entry in the look-up table...

```
if (lookup_table.empty()) {
    lookup_table["goofy"] = Goofy::create;
    lookup_table["pluto"] = Pluto::create;
    lookup_table["donal duck"] = DonalDuck::create;
}
```

  ... in the `DisneyFactory` class implementation

- Using non-local variable initialization we can avoid step 2!

Factory with automatic registration

- The `DisneyFactory` shall contain the logic to register the creation method in the look-up table.
- This registration is performed at run-time and at start-up
- But where do we write this code?
- In the constructor, of course!

FactoryExample5.h

```
class DisneyFactory {
public:
        typedef DisneyProduct* (*creator_type_t)(void);

        DisneyFactory(const std::string& id, creator_type_t func);
        static DisneyProduct* create(const std::string& id);
private:
        static std::map<std::string, creator_type_t> lookup_table;
};
```


Factory with automatic registration

FactoryExample5.cc

```
map<std::string, DisneyFactory::creator_type_t> DisneyFactory::lookup_table;

DisneyFactory::DisneyFactory(const string& id, creator_type_t func)
{
        cout << "Factory: registrating creator for id=" << id << endl;
        if (lookup_table.find(id) != lookup_table.end()) {
                cout << "Error: ID already in look-up table" << endl;
                return;
        }
        lookup_table[id] = func;
}

DisneyProduct* DisneyFactory::create(const string& id)
{
        if (lookup_table.find(id) == lookup_table.end())
                return NULL;
        return lookup_table[id]();
}
```

Factory with automatic registration

- Each concrete `DisneyProduct` class shall automatically register itself...
- just defining a non-local variable with static storage duration of type `DisneyFactory`.

```
class Goofy : public DisneyProduct {
public:
    static DisneyProduct* create(void) { return new Goofy(); };
private:
    Goofy() : DisneyProduct("goofy") {};
};

// In the implementation file...

DisneyFactory register_goofy("goofy", Goofy::create);
```

The full example is:
`./examples/10.real-application_moreOnCreation-examples/FactoryE`

Initialization order

"Variables with ordered initialization defined within a single translation unit shall be initialized in the order of their definitions in the translation unit."

[C++11 standard: n3242, sec 3.6.2, par 2]

In other words:

- global variables are initialized following the order of appearance in the source file;
- but the initialization order is not guaranteed between variables of different source files!

Initialization order fiasco

`Goofy.cc`

```
class Goofy : public DisneyProduct {
public:
    static DisneyProduct* create(void) { return new Goofy(); };
private:
    Goofy() : DisneyProduct("goofy") {};
};

DisneyFactory reg("goofy", Goofy::create);
```

`DisneyFactory.cc`

```
map<std::string, DisneyFactory::creator_type_t>
                                        DisneyFactory::lookup_table;

DisneyFactory::DisneyFactory(const string& id, creator_type_t func)
{
    if (lookup_table.find(id) != lookup_table.end()) {
            cout << "Error: already in look-up table" << endl;
            return;
    }
    lookup_table[id] = func;
}
```


How to prevent the fiasco

The problem of previous example:

- If `DisneyFactory::lookup_table` is not initialized before the non-local object `reg` ...
- then the call to the constructor (registration mechanism) `DisneyFactory::DisneyFactory(...)` fails!

Solution for the previous example?

- Make `DisneyFactory::lookup_table` a pointer to `map` rather than a `map` object.
- As a pointer it shall be zero-initialized (static initialization) before any dynamic initialization.
- Delay the creation of the actual map until it is necessary: when it is used by `DisneyFactory::DisneyFactory(...)`.

How to prevent the fiasco

`DisneyFactory.cc`

```
map<std::string, DisneyFactory::creator_type_t>*
                                        DisneyFactory::lookup_table;

DisneyFactory::DisneyFactory(const string& id, creator_type_t func)
{
    if (!lookup_table)
        lookup_table = new map<std::string, creator_type_t>();
    if (lookup_table->find(id) != lookup_table->end()) {
            cout << "Error: already in look-up table" << endl;
            return;
    }
    (*lookup_table)[id] = func;
}
```

The generalization of this approach is known as *“Construct On First Use idiom”*.

Construct On First Use Idiom

Objective:

- Ensure that an object is initialized before its first use.
- Specifically, ensure that a non-local static object is initialized before its first use.

Solution:

- Encapsulate the creation of the “critical” object in a function.
- Basically the object is now a **local** variable with static storage duration which is initialized **only** when the function is called!
- Also known as lazy initialization/evaluation (not at startup)

```
MyClass& getMyObj()
{
  static MyClass* p = new MyClass;
  return *p;
}
```

Example [http://www.parashift.com/c++-faq-lite/ctors.html]

x.cc

```
#include "Fred.h"
Fred x;
```

y.cc

```
#include "Barney.h"
Barney y;
```

Barney.cc

```
#include "Barney.h"
Barney::Barney()
{
    //...
    x.goBowling();
    //...
}
```

x.cc

```
#include "Fred.h"

Fred& x()
{
    static Fred* ans = new Fred();
    return *ans;
}
```

Barney.cc

```
#include "Barney.h"

Barney::Barney()
{
    //...
    x().goBowling();
    //...
}
```


Alternative implementation...

Dynamic allocation

```
#include "Fred.h"

Fred& x()
{
    static Fred* ans = new Fred();
    return *ans;
}
```

- The destructor for `ans` is not called, ever!
- Not good if destructor is non-trivial.

Local static

```
#include "Fred.h"

Fred& x()
{
    static Fred ans;
    return ans;
}
```

- The destructor for `ans` is called on program termination.
- Might generate destruction order fiasco!

`DataFactory` with automatic registration

- The `DataFactory` class shall have a constructor to register the creator functions.
- The creator functions shall be defined by each concrete data-class:
  - `DataInt8`
  - `DataUInt16`
  - `DataFloat32`
  - `...`
- A utility macro might be used to generate the code for the creator function given a public constructor.

The full example is:
`./examples/10.real-application_moreOnCreation-examples/DataExam`

Consideration

- What about *extensibility*?
- Adding new `Data` requires the following modifications:
  1. definition of the new concrete `Data` (e.g. `DataFloat64`, `DataImageRGB`)
  2. adding the automatic registration (one line if using the macro)

Notice:

- Both changes are to the implementation file of the new class!
- No more changes are required to other files!

Different creation parameters

- We have now an extensible solution with respect to new `Data`.
- However, the creation function accepts always the same parameters!

DataExample6/DataFactory.h

```
class DataFactory {
public:
        typedef Data* (*creator_type_t)(const std::string&, unsigned long);

        DataFactory(const std::string& id, creator_type_t func);
```

- Fine for basic data types...

DataExample6/DataInt8.h

```
class DataInt8 : public DataTemplate<int8_t> {
public:
        DataInt8(const std::string& name, unsigned long len);
};
```


Different creation parameters

- Consider the `DataImageRGB` example...
- a new concrete data to manage images in RGB format

```
class DataImageRGB : public Data {
public:
     DataImageRGB(const std::string& name, unsigned long len, unsigned width, unsigned height) :
        Data("ImageRGB", name, width * height * 3, len)
    {
        // Allocate internal representation
        // for RGB image with resolution 'width' x 'height'
        // ...
    };
    ~DataImageRGB()
    {
        // Deallocations...
    };

    unsigned long format_data(const uint8_t* buff, unsigned long len)
    {
        // Formatting...
    };
    // ...
};
```

- The constructor requires two more params: `width` and `height`

Different creation parameters

The parameters `width` and `height` should be coded in the XML configuration file

```
<message_description>
   <data data_type="imageRGB" data_name="data_name_3" data_len="1">
       <RGB_config width="160" height="120">
   </data>
</message_description>
```

Problem: is the configuration logic: DataExample5-to-exercise-solution/FormatHandler.cc

```
FormatHandler::FormatHandler()
{
        // We create the data vector according to XML config
        vector<XmlDataElement> config = parse_xml_data();

        vector<XmlDataElement>::const_iterator it;
        for (it = config.begin(); it != config.end(); ++it) {
                Data *d = DataFactory::create(it->type, it->name, it->len);
                if (!d) {
                        cout << "Unable to create data type = '" << it->type <<
                                "' ! Skipping" << endl;
                        continue;
                }
                data_vector.push_back(d);
        }
}
```

Solution:

- Delegate the XML parsing to the Factory...
- and to enforce extensibility, eventually delegate to the concrete data class!

duck-lab approach

The solution adopted in the *duck-lab* uses a "two-way factory":

- A `Parser` class is defined to access the XML
- A `DataConfig` class is defined to store the config information retrieved through the `Parser`
- The `Data` class is created from the `DataConfig`

Motivation: separating the concrete `Data` class from its configuration.