Dynamic Memory Management
Class Destructors
constant member functions

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Using Class Constructors

```
#include <vector>
Using std::vector;

Datum average(vector<float>&  val,
vector<float>& err) {
  double mean = 0.;
  double meanErr(0.); // same as = 0.

  // loop over data
    // compute average

  Datum  res(mean, meanErr);
  return res;
}
```

Constructor is called with arguments
Same behavior for **`double`** and **`Datum`**

Object **`res`** is like any other variable **`mean`** or **`meanErr`**
`res` simply returned as output to caller

```
#include <vector>
Using std::vector;

double average(vector<float>&  val) {
  double mean = 0.;
    // loop over data
    // compute average

  return mean;
}
```

```
#include <vector>
Using std::vector;

Datum average(vector<float>&  val,
vector<float>& err) {
  double mean = 0.;
  double meanErr(0.); // same as = 0.

  // loop over data
    // compute average

  return Datum(mean, meanErr);
}
```

Since **`res`** not really needed within function
we can just create it while returning the function output

Today's Lecture

- Dynamic allocation of memory
- Destructors of a class
- Constant member functions
- Default arguments for member functions

Dynamic Memory Allocation: **new** and **delete**

- C++ allows dynamic management memory at run time via two dedicated operators: **new** and **delete**

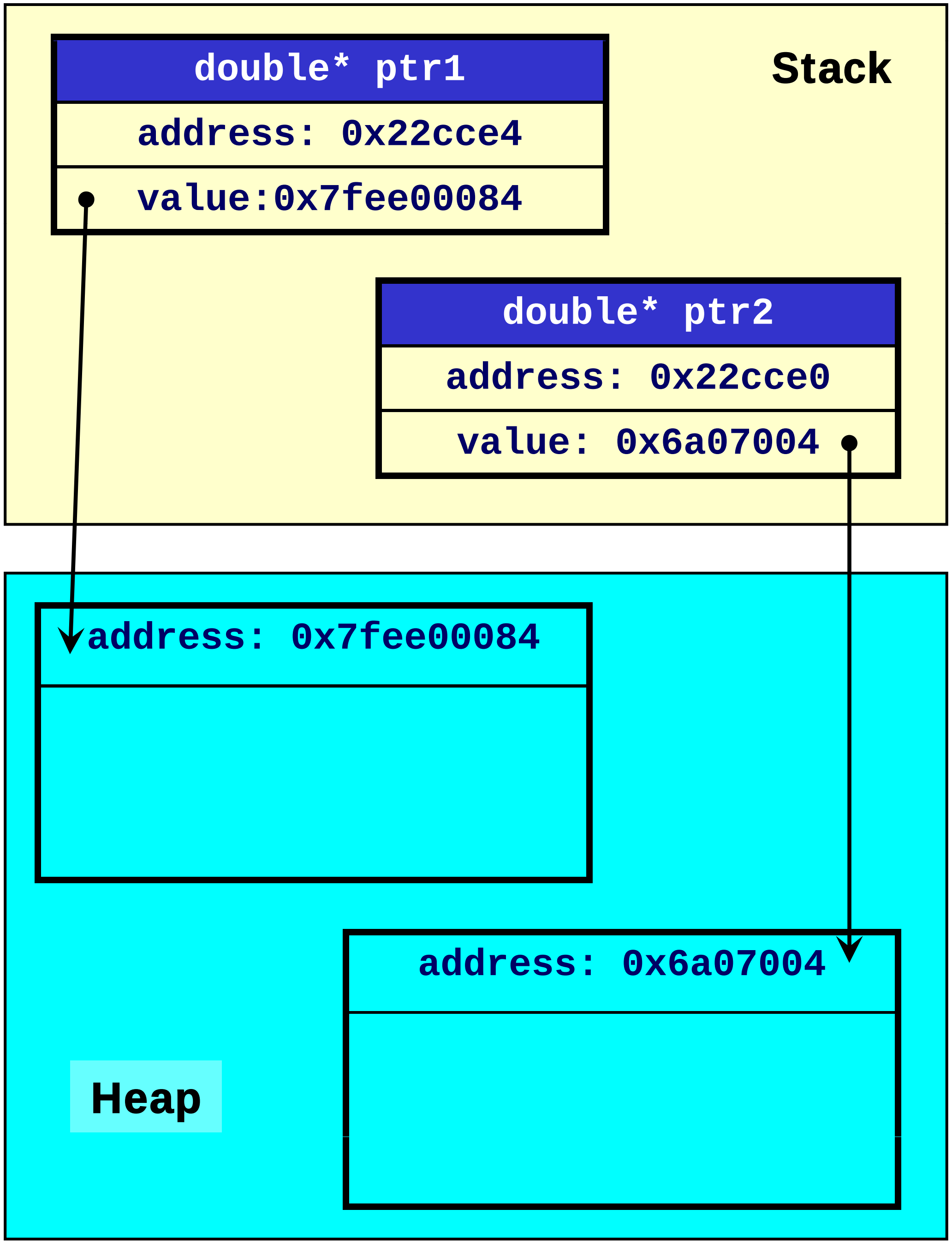
- **new**: allocates memory for objects of any built-in or user-defined type
  - The amount of allocated memory depends on the size of the object
  - For user-defined types the size is determined by the data members

- Which memory is used by **new**?
  - **new** allocated objects in the free store also known as heap
  - This is region of memory assigned to each program at run time
  - Memory allocated by **new** is unavailable until we free it and give it back to system via **delete** operator
- **delete**: de-allocates memory used by new and give it back to system to be re-used

Stack and Heap

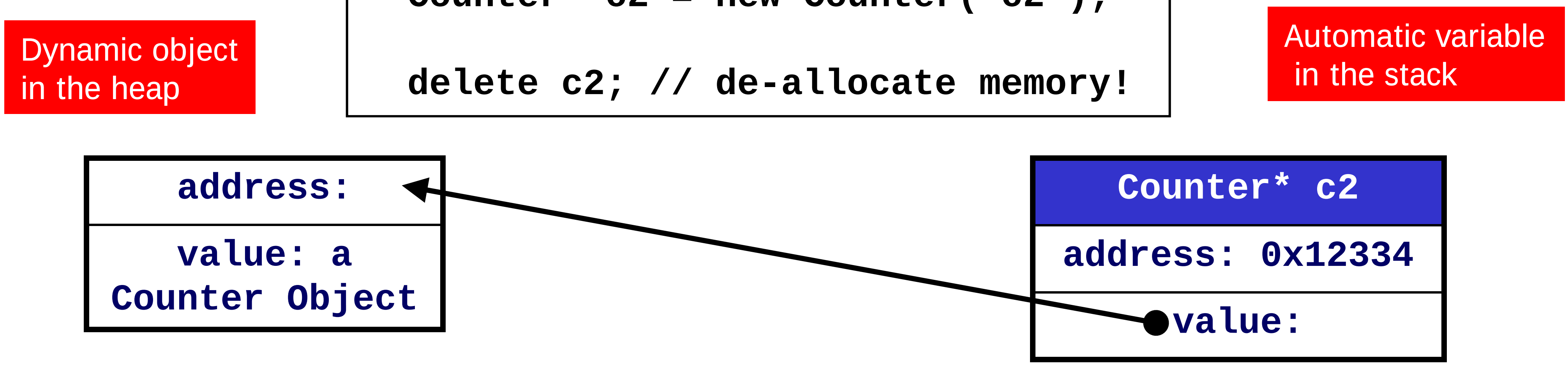
```
// app7.cpp
#include <iostream>
using namespace std;

int main() {
    double* ptr1 = new double[100000];
    ptr1[0] = 1.1;

    cout << "ptr1[0]: " << ptr1[0]
         << endl;

    int* ptr2 = new int[1000];
    ptr2[233] = -13423;

    cout << "&ptr1: "<< &ptr1
     << "  sizeof(ptr1): " << sizeof(ptr1)
     << "  ptr1: " << ptr1 << endl;

    cout << "&ptr2: "<< &ptr2
     << "  sizeof(ptr2): " << sizeof(ptr2)
     << " ptr2: " << ptr2 << endl;
    delete[] ptr1;
    delete[] ptr2;
    return 0;
}
```

```
$ g++ -Wall -o app7 app7.cpp
$ ./app7
ptr1[0]: 1.1
&ptr1: 0x22cce4  sizeof(ptr1): 4
ptr1: 0x7fee0008
&ptr2: 0x22cce0  sizeof(ptr2): 4
ptr2: 0x6a0700
```



What does **new** do?

```
Counter* c2 = new Counter("c2");

delete c2; // de-allocate memory!
```



- new allocates an amount of memory given by sizeof(Counter) somewhere in memory
- returns a pointer to this location
- we assign c2 to be this pointer and access the dynamically allocated memory
- delete de-allocates the region of memory pointed to by c2 and makes this memory available to be re-used by the program

Memory Leak: Killing the System

- Perhaps one of the most common problems in C++ programming

- User allocates memory at run time with new but never releases the memory – forgets to call delete!

- Golden rule: every time you call **`new`** ask yourself “where and when **`delete`** is called to free this memory” ?

- Even small amount of leak can lead to a crash of the system
  - Leaking 10 kB in a loop over 1M events leads to 1 GB of allocated and un-usable memory!

Simple Example of Memory Leak

```
// app6.cpp
#include <iostream>
using namespace std;

int main() {

  for(int i=0; i<10000; ++i){

    double* ptr = new double[100000];
    ptr[0] = 1.1;

    cout << "i: " << i
         << ", ptr: " << ptr
         << ", ptr[0]: " << ptr[0]
         << endl;

    // delete[] ptr; // ops! memory leak!
  }
  return 0;
}
```

```
$ g++ -o leak1 leak1.cpp
$ ./leak1
i: 0, ptr: 0x4a0280, ptr[0]: 1.1
i: 1, ptr: 0x563bf8, ptr[0]: 1.1
…
i: 1381, ptr: 0x4247e178, ptr[0]: 1.1
i: 1382, ptr: 0x42541680, ptr[0]: 1.1
Abort (core dumped)
```

- At each iteration ptr is a pointer to a new (and large) array of 100k doubles!
- This memory is not freed because we forgot the delete operator!
- At each turn more memory becomes unavailable until the system runs out of memory and crashes!

Advantages of Dynamic Memory Allocation

- No need to fix size of data to be used at compilation time
  - Easier to deal with real life use cases with variable and unknown number of data objects
  - No need to reserve very large but FIXED-SIZE arrays of memory
  - Example: interaction of particle in matter
    - How many particles are produced due to particle going through a detector?
    - Number not fixed a priori
    - Use dynamic allocation to create new particles as they are generated

- Disadvantage: correct memory management
  - Must keep track of ownership of objects
  - If not de-allocated can cause memory leaks which leads to slow execution and crashes
  - Most difficult part specially at the beginning or in complex systems

Destructor Method of a Class

- Constructor used by compiler to initialize instance of a class (an object)
  - Assign proper values to data members and allocate the object in memory

- Destructors are Special member function doing reverse work of constructors
  - Do cleanup when object goes out of scope

- Destructor performs termination house keeping when objects go out of scope
  - No de-allocation of memory
  - Tells the program that memory previously occupied by the object is again free and can be re-used

- Destructors are FUNDAMENTAL when using dynamic memory allocation

Special Features of Destructors

- Destructors have no arguments

- Destructors do not have a return type
  - Similar to constructors

- Destructor of class Counter MUST be called ~Counter()

```
#ifndef Counter_h_
#define Counter_h_
// Counter.h
#include <string>

class Counter {
  public:
    Counter(const std::string& name);
    ~Counter();
    int value();
    void reset();
    void increment();
    void increment(int step);
    void print();

  private:
    int count_;
    std::string name_;
};
#endif
```

Trivial Example of Destructor

Constructor initializes data members

```
#ifndef Counter_h_
#define Counter_h_
// Counter.h
#include <string>

class Counter {
  public:
    Counter(const std::string& name);
    ~Counter();
    int value();
    void reset();
    void increment();
    void increment(int step);
    void print();

  private:
    int count_;
    std::string name ;
};
#endif
```

Destructor does nothing

```
#include "Counter.h"
#include <iostream> // needed for input/output
using std::cout;
using std::endl;

Counter::Counter(const std::string& name) {
  count_ = 0;
  name_ = name;
  cout << "Counter::Counter() called for Counter "
       << name_ << endl;
};

Counter::~Counter() {
  cout << "Counter::~Counter() called for Counter "
       << name_ << endl;
};

int Counter::value()  {
  return count_;
}

void Counter::reset() {
  count_ = 0;
}

void Counter::increment() {
  count_++;
}

void Counter::increment(int step) {
  count_ = count_+step;
}

void Counter::print() {
  cout << "Counter::print(): name: " << name_
       << "  value: " << count_ << endl;
}
```

Who and When Calls the Destructor?

Constructors are called by compiler when new objects are created

```
// app1.cpp
#include "Counter.h"
#include <string>

int main() {

  Counter c1( std::string("c1") );
  Counter c2( std::string("c2") );
  Counter c3( std::string("c3") );

  c2.increment(135);
  c1.increment(5677);

  c1.print();
  c2.print();
  c3.print();

  return 0;
}
```

Destructors are called implicitly by compiler when objects go out of scope!

Destructors are called in reverse order of creation

```
$ g++ -c Counter.cc
$ g++ -o app1 app1.cpp Counter.o
$ ./app1
Counter::Counter() called for Counter c1
Counter::Counter() called for Counter c2
Counter::Counter() called for Counter c3
Counter::print(): name: c1  value: 5677
Counter::print(): name: c2  value: 135
Counter::print(): name: c3  value: 0
Counter::~Counter() called for Counter c3
Counter::~Counter() called for Counter c2
Counter::~Counter() called for Counter c1
```

Create in order objects c1, c2, and c3

Destruct c3, c2, and c1

Another Example of Destructors

```
// app2.cpp
#include "Counter.h"
#include <string>

int main() {

  Counter c1( std::string("c1") );

  int count = 344;

  if( 1.1 <= 2.02 ) {
    Counter c2( std::string("c2") );

    Counter c3( std::string("c3") );
    if( count == 344 ) {
      Counter c4( std::string("c4") );
    }

    Counter c5( std::string("c5") );

    for(int i=0; i<3; ++i) {
      Counter c6( std::string("c6") );
    }
  }

  return 0;
}
```

```
$ g++ -o app2 app2.cpp Counter.o
$ ./app2
Counter::Counter() called for Counter c1
Counter::Counter() called for Counter c2
Counter::Counter() called for Counter c3
Counter::Counter() called for Counter c4
Counter::~Counter() called for Counter c4
Counter::Counter() called for Counter c5
Counter::Counter() called for Counter c6
Counter::~Counter() called for Counter c6
Counter::Counter() called for Counter c6
Counter::~Counter() called for Counter c6
Counter::Counter() called for Counter c6
Counter::~Counter() called for Counter c6
Counter::~Counter() called for Counter c5
Counter::~Counter() called for Counter c3
Counter::~Counter() called for Counter c2
Counter::~Counter() called for Counter c1
```

Using **new** and **delete** Operators

```
// app6.cpp
#include "Counter.h"
#include "Datum.h"
#include <iostream>
using namespace std;

int main() {

  Counter c1("c1");

  Counter* c2 = new Counter("c2");
  c2->increment(6);

  Counter* c3 = new Counter("c3");

  Datum d1(-0.3,0.07);

  Datum* d2 = new Datum( d1 );
  d2->print();

  delete c2; // de-allocate memory!
  delete c3; // de-allocate memory!
  delete d2;

  return 0;
}
```

```
$ g++ -o app6 app6.cpp Datum.o Counter.o
$ ./app6
Counter::Counter() called for Counter c1
Counter::Counter() called for Counter c2
Counter::Counter() called for Counter c3
datum: -0.3 +/- 0.07
Counter::~Counter() called for Counter c2
Counter::~Counter() called for Counter c3
Counter::~Counter() called for Counter c1
```

Order of calls to destructors has changed!

delete calls explicitly the destructor of the object to de-allocate memory

Vital for objects holding pointers to dynamically allocated memory

Why no message when destructing d2 ?

`constant` Member Functions

- Enforce principle of least privilege
  - Give privilege ONLY if needed

- **`const`** member functions cannot
  - modify data members
  - cannot be called on non-constant objects

- **`const`** member functions tell user, the function only ‘uses’ the input data or data members but makes no changes

- Pay attention which function can be called on which objects
  - Objects can be constant
    - You can not modify a constant object
    - calling non-constant methods on constant objects does not make sense!

Datum Class and const Member Functions

```
class Datum {
  public:
    Datum();
    Datum(double x, double y);
    Datum(const Datum& datum);

    double value() { return value_; }
    double error() { return error_; }
    double significance();
    void print();

    void setValue(double x) { value_ = x; }
    void setError(double x) { error_ = x; }

  private:
    double value_;
    double error_;
};
```

Which methods could become constant?

Datum Class with const Methods

All methods that only return valuea and do not change the attributes of an object!

All getters can be constant

```
#ifndef Datum1_h
#define Datum1_h
// Datum1.h
#include <iostream>
using namespace std;

class Datum {
  public:
    Datum();
    Datum(double x, double y);
    Datum(const Datum& datum);

    double value() const { return value_; }
    double error() const { return error_; }
    double significance() const;
    void print() const;

    void setValue(double x) { value_ = x; }
    void setError(double x) { error_ = x; }

  private:
    double value_;
    double error_;
};
#endif
```

what about setter methods?

```
#include "Datum1.h"
#include <iostream>
Datum::Datum() {
  value_ = 0.; error_ = 0.;
}
Datum::Datum(double x, double y) {
  value_ = x; error_ = y;
}
Datum::Datum(const Datum& datum) {
  value_ = datum.value_;
  error_ = datum.error_;
}
double
Datum::significance() const {
  return value_/error_;
}
void Datum::print() const {
  using namespace std;
  cout << "datum: " << value
       << " +/- " << error_ << endl;
}
```

Typical error with constant methods

```
#ifndef Datum2_h
#define Datum2_h
// Datum2.h
#include <iostream>
using namespace std;

class Datum {
  public:
    Datum();
    Datum(double x, double y);
    Datum(const Datum& datum);

    double value() const { return value_; }
    double error() const { return error_; }
    double significance() const;
    void print() const;

    void setValue(double x) const { value_ = x; }
    void setError(double x) const { error_ = x; }

  private:
    double value_;
    double error_;
};
#endif
```

setters can never be constant!

Setter method is used to modify data members

Similarly constructors and destructors can not be constant

```
$ g++ -c Datum2.cc
In file included from Datum2.cc:1:
Datum2.h: In member function `void Datum::setValue(double) const':
Datum2.h:18: error: assignment of data-member `Datum::value_' in read-only structure
Datum2.h: In member function `void Datum::setError(double) const':
Datum2.h:19: error: assignment of data-member `Datum::error_' in read-only structure
```

Example of Error using non-constant functions

```
#ifndef Datum4_h
#define Datum4_h
// Datum4.h
#include <iostream>
#include <string>
using namespace std;

class Datum {
  public:
    Datum();
    Datum(double x, double y);
    Datum(const Datum& datum);

    double value() const { return value_; }
    double error() const { return error_; }
    double significance() const;

    void print(const std::string& comment) ;
    void setValue(double x) { value_ = x; }
    void setError(double x) { error_ = x; }
  private:
    double value_;
    double error_;
};
#endif
```

```
void Datum::print(const std::string& comment) {
  using namespace std;
  cout << comment << ": " << value_
       << " +/- " << error_ << endl;
}
```

print MUST have been constant!

bad design of the class!

```
// app1.cpp

#include "Datum4.h"

int main() {

  Datum d1(-67.03, 32.12 );
  const Datum d2(-67.03, 32.12 );

  d1.print("datum");

  d2.print("const datum");

  return 0;
}
```

```
$ g++ -o app1 app1.cpp Datum4.o
app1.cpp: In function `int main()':
app1.cpp:12: error: passing `const Datum' as `this'
argument of `void Datum::print(const std::string&)'
discards qualifiers
```

Default Values for Methods

- Functions (not only member functions in classes) might be often invoked with recurrent values for their arguments

- It is possible to provide default values for arguments of any function in C++
  - Default arguments must be provided the first time the name of the function occurs
    - In declaration if separate implementation
    - In definition if the function is declared and defined at the same time

- Only the right-most argument can be omitted
  - Including all arguments to the right of omitted argument

Example of Default Values

```
// Counter.h

class Counter {
  public:
    Counter();
    int value();
    void reset();
    void increment();
    void increment(int step);

  private:
    int count_;
};
```

Two increment() methods
but very similar functionality

increment() is a special case of
increment(int step) with step=1

Why two different methods?

```
// Counter.cc
// include class header files
#include "Counter.h"

// include any additional header files
//  needed in the class
// definition
#include <iostream>
using std::cout;
using std::endl;

Counter::Counter() {
  count_ = 0;
};

int Counter::value()  {
  return count_;
}

void Counter::reset() {
  count_ = 0;
}

void Counter::increment() {
  count_++;
}

void Counter::increment(int step) {
  count_ = count_+step;
}
```

Default Value for `Counter::increment(int step)`

```
#ifndef Counter_Old_h_
#define Counter_Old_h_
// CounterOld.h

class Counter {
  public:
    Counter();
    int value();
    void reset();
    void increment(int step = 1);
  private:
    int count_;
};
#endif
```

Bad Practice!
Name of class different from name of file

```
// CounterOld.cc
#include "CounterOld.h"
#include <iostream>
using std::cout;
using std::endl;

Counter::Counter() {
  count_ = 0;
};

int Counter::value()  {
  return count_;
}

void Counter::reset() {
  count_ = 0;
}

void Counter::increment(int step) {
  count_ = count_+step;
}
```

```
// app3.cpp
#include "CounterOld.h" // old counter class
#include <iostream>
using namespace std;

int main() {

  Counter c1;

  c1.increment(); // no argument
  cout << "counter: " << c1.value() << endl;

  c1.increment(14); // provide argument, same function
  cout << "counter: " << c1.value() << endl;

  return 0;
}
```

```
$ g++ -c CounterOld.cc
$ g++ -o app3 app3.cpp CounterOld.o
.$ ./app3
counter: 1
counter: 15
```

Ambiguous Use of Default Arguments

```
#ifndef Datum_h
#define Datum_h
// Datum.h
#include <iostream>
using namespace std;

class Datum {
  public:
    //Datum();
    Datum(double x=1.0, double y=0.0);
    Datum(const Datum& datum);
    double value() { return value_; }
    double error() { return error_; }
    double significance();

  private:
    double value_;
    double error_;
};
#endif
```

```
#include "Datum.h"

Datum::Datum(double x, double y) {
  value_ = x;
  error_ = y;
}

Datum::Datum(const Datum& datum) {
  value_ = datum.value_;
  error_ = datum.error_;
}

double
Datum::significance() {
  return value_/error_;
```

Does it make sense to have default value and error? Depends on use case

```
#include "Datum.h"
int main() {

  Datum d1(-0.23, 0.05); // provide arguments
  d1.print();

  Datum d2(5.23); // default error ...
  d2.print();

  Datum d3; // default value and error!
  d3.print();
  return 0;
}
```

```
$ g++ -c Datum.cc
$ g++ -o app4 app4.cpp Datum.o
$ ./app4
datum: -0.23 +/- 0.05
datum: 5.23 +/- 0
datum: 1 +/- 0
```

Don’t Abuse Default Arguments!

- Default values must be used for functions very similar in functionality and with obvious default values

- If default values are not intuitive for user think twice before using them!

- Quite often different constructors correspond to DIFFERENT ways to create an object
  - Default values could be misleading

- If arguments are physical quantities ask yourself: is the default value meaningful and useful for everyone?