HIGH-LEVEL PROGRAMMING 2

Dynamic Memory in C++ by Prasanna Ghali

Heap Memory Allocation & Deallocation Functions: <cstdlib>

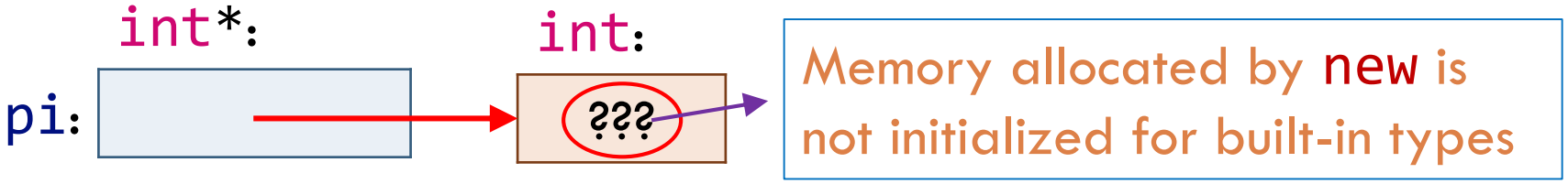

```
// declared in <cstdlib>
namespace std {

// functions for dynamically allocating heap memory
void *malloc(size_t size);
void *calloc(size_t count, size_t size);
void *realloc(void *ptr, size_t size);

// function for returning dynamically allocated
// memory back to heap
void free(void *ptr);

}
```

Program Memory Layout

Free Store Allocation

- We request memory to be allocated on free store for individual element by `new` operator
  - `new` operator returns pointer to allocated memory
  - Pointer value is address of first byte of the memory
  - Pointer points to an object of specified type

```
int *pi = new int;
```



Initialization of Allocated Memory

- Memory allocated by new is not initialized for built-in types
- You can change that using { } for initialization

```
int *pi     = new int{11};   // ok: modern C++
int *pi2    = new int(12.1); // ok: old-style C++
int *pi3    = new int();     // ok: initialize to 0
int *pi4    = new int{12.1}; // error
double *pd = new double {11.1}; // ok
```

The null Pointer

- If you've no other pointer to use for initializing a pointer, use null pointer `nullptr`
- Name `nullptr` for null pointer is new in C++11 – in older code, people often use `0` (zero) or `NULL`

```
double *pd = nullptr; // the null pointer
// some code here ...
if (pd != nullptr) // consider pd valid

// even shorter ...
if (pd) // consider pd valid
```

Free Store Deallocation

- For large programs and for long-running programs, freeing of memory for reuse is essential!!!

```
// leaks memory
double foo(int res_size) {
  double acc{};

  for (int i{}; i < res_size; ++i) {
    double *p = new double;
    // use p to calculate results to be put in res
    acc += *p;
  }
  return acc;
}
```

Free Store Deallocation

- Operator for returning memory obtained by `new` back to free store is called `delete`

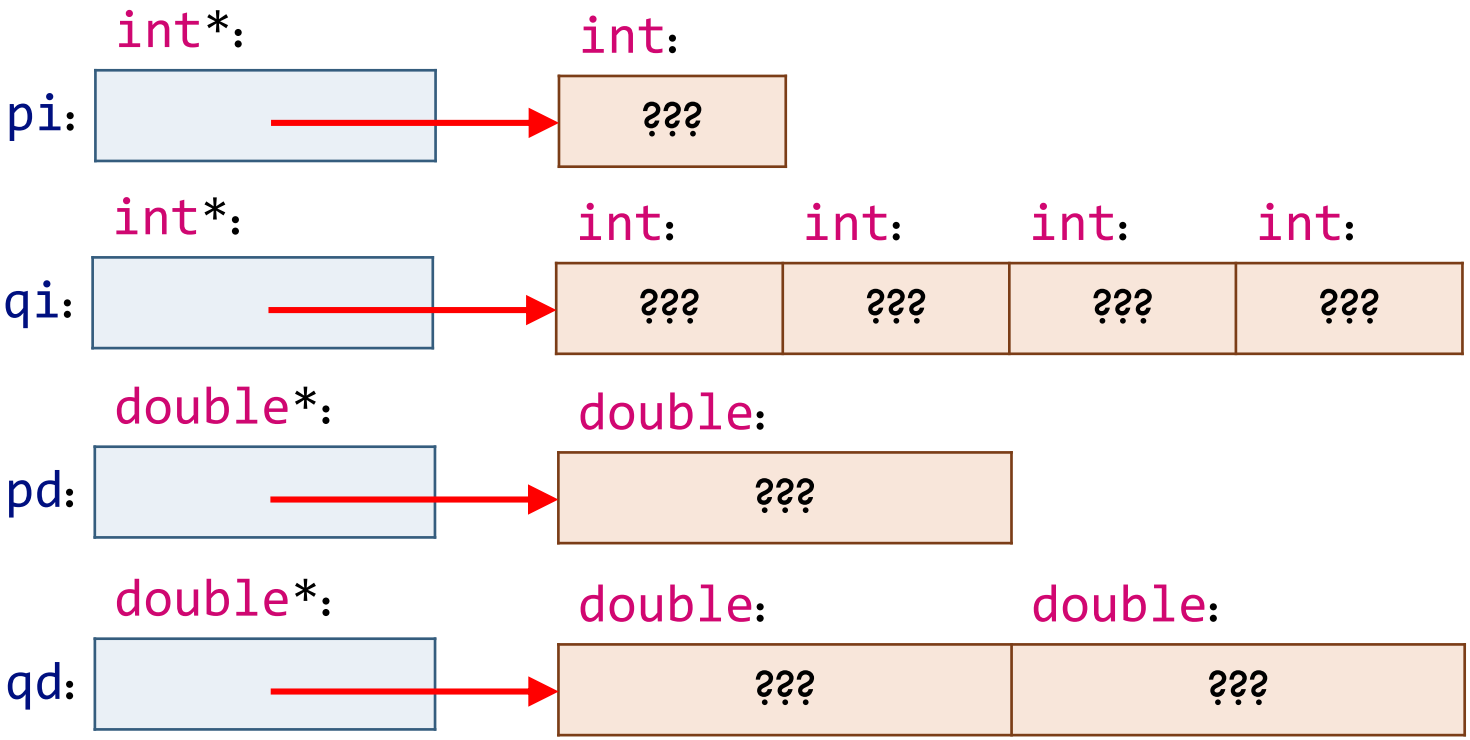
```
// doesn't leak memory anymore...
double foo(int res_size) {
  double acc{};

  for (int i{}; i < res_size; ++i) {
    double *p = new double;
    // use p to calculate results to be put in res
    acc += *p;
    delete p;
  }
  return acc;
}
```

Free Store Allocation of Array

- We request memory to be allocated on free store for sequences [arrays] of elements by `new[]` operator
  - `new[]` operator returns pointer to allocated memory
  - Pointer value is address of first byte of the memory
  - Pointer points to an object of specified type
  - Pointers does *not* know how many elements it points to

Free Store Allocation of Array


```
int *pi     = new int;       // allocate one int
int *qi     = new int[4];    // allocate array of 4 ints
double *pd = new double;     // allocate one double
double *qd = new double[2]; // allocate array of 2 doubles
```



Initialization

- We can specify initializer list for array of objects allocated by new[ ]

```
int *pai1 = new int [5] {1,2,3,4,5};
int *pai2 = new int []  {11,22,33,44,55};

double *pad3 = new double [4] {1, 2, 3, 4};
double *pad4 = new double [3] {1.1, 2.2, 3.3};
```

Doesn't compile in g++ but compiles in clang++ and cl [Microsoft]

Free Store Deallocation

- Operator for returning memory obtained by `new[]` back to free store is called `delete[]`

```
double* calc(int res_size, int max) {
  double *p = new double[max];
  // caller responsible for memory allocated for res
  double *res = new double[res_size];
  // use p to calculate results to be put in res
  delete[] p;
  return res;
}

double *r = calc(100, 1000);
// use r ...
delete[] r; // don't need memory anymore: free it
```

Memory Exhaustion

- Beware!!! Unlike `malloc`, `new` and `new[]` don't return `nullptr` when free store memory is exhausted!!!
- Instead, they throw `std::bad_alloc` exception [exceptions are covered in 2nd half of semester]
- See *exhaust.cpp* where check for `nullptr` fails when free store is exhausted
- Since exiting or aborting our program is only option when free store is exhausted, it doesn't much matter!!!

Caveat: Don't Use C Standard Library!!!

- Unlike `malloc` and `free`, `new` and `new[]` know about constructors while `delete` and `delete[]` know about destructors
- `malloc` just allocates memory while `new` allocates memory and *then calls appropriate constructor to initialize allocated object*
- `free` just deallocates memory while `delete` *calls destructor* and then deallocates memory
- Recall that built-in types don't have ctors and dtors
- See *num.hpp, num.cpp, num-driver.cpp*

Caveat: Don't Mix C and C++ Concepts!!!

- Don't use `free` on pointers that point to memory returned by `new` or `new[]`
- Don't use `delete` or `delete[]` on pointers that point to memory returned by `malloc`

Caveat: Don't Mix Different Forms Of `new` And `delete`

- Two forms of `new`
  - `new p` allocates memory for individual object
  - `new[] p` allocates memory for array of objects
- Two forms of `delete`
  - `delete p` frees memory for individual object allocated by `new`
  - `delete[] p` frees memory for array of objects allocated by `new[]`
- *It is programmer's tedious job to use right version*

Pointers Are Error Prone

- Dereferencing uninitialized pointers
- Dereferencing `nullptr`s
- Reading uninitialized objects that are dynamically allocated
- Failing to `delete` [or `delete[]`] allocated memory causing memory leak
- Calling `delete` rather than `delete[]` and vice versa
- Accessing `delete`d memory
- Double `delete`ing dynamically allocated objects
- Premature deletion causes dangling pointers
- Off-by-one array subscripting

Pointers Are Error Prone

- Use Valgrind to debug memory bugs!!!
- See handout and source file more lots of examples!!!