Generics

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Goals of this Lecture

- Help you learn about:
  - Generic modules
    - Data structures that can store multiple types of data
    - Functions that can work on multiple types of data
  - How to create generic modules in C
    - Which wasn't designed with generic modules in mind!
- Why?
  - Reusing existing code is easier/cheaper than writing new code; reuse reduces software costs
  - Generic modules are more reusable than non-generic ones
  - A power programmer knows how to create generic modules
  - A power programmer knows how to use existing generic modules to create large programs

Generic Data Structures Example

- Recall Stack module from last lecture

```
/* stack.h */

typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void  Stack_free(Stack_T s);
void  Stack_push(Stack_T s, const char *item);
char *Stack_top(Stack_T s);
void  Stack_pop(Stack_T s);
int   Stack_isEmpty(Stack_T s);
```

- Items are strings (type char*)

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Generic Data Structures Example

- Stack operations (push, pop, top, etc.) make sense for items ***other than*** strings too
- So Stack module could (and maybe should) be generic
- Problem: How to make Stack module generic?
  - How to define Stack module such that a Stack object can store items ***of any type***?

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Generic Data Structures via typedef

- Solution 1: Let clients define item type

```
/* client.c */

struct Item {
   char *str; /* Or whatever is appropriate */
};

…
Stack_T s;
struct Item item;

item.str = "hello";
s = Stack_new();
Stack_push(s, item);
…
```

```
/* stack.h */

typedef struct Item *Item_T;
typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void    Stack_free(Stack_T s);
void    Stack_push(Stack_T s, Item_T item);
Item_T  Stack_top(Stack_T s);
void    Stack_pop(Stack_T s);
int     Stack_isEmpty(Stack_T s);
```

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Generic Data Structures via typedef

- Problem: Awkward for client to define structure type and create structures of that type
- Problem: Client (or some other module in same program) might already use “Item_T” for some other purpose!
- Problem: Client might need two Stack objects holding different types of data!!!
- We need another approach…

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Generic Data Structures via void*

- Solution 2: The generic pointer (void*)

```
/* stack.h */

typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void    Stack_free(Stack_T s);
void    Stack_push(Stack_T s, const void *item);
void   *Stack_top(Stack_T s);
void    Stack_pop(Stack_T s);
int     Stack_isEmpty(Stack_T s);
```

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Generic Data Structures via void*

- Can assign a pointer of any type to a void pointer

```
/* client.c */

…
Stack_T s;
s = Stack_new();
Stack_push(s, "hello");
…
```

OK to match an actual parameter of type char* with a formal parameter of type void*

```
/* stack.h */

typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void    Stack_free(Stack_T s);
void    Stack_push(Stack_T s, const void *item);
void   *Stack_top(Stack_T s);
void    Stack_pop(Stack_T s);
int     Stack_isEmpty(Stack_T s);
```

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Generic Data Structures via void*

- Can assign a void pointer to a pointer of any type

```
/* client.c */

char *str;
…
Stack_T s;
s = Stack_new();
Stack_push(s, "hello");
…
str = Stack_top(s);
```

OK to assign a void* return value to a char*

```
/* stack.h */

typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void    Stack_free(Stack_T s);
void    Stack_push(Stack_T s, const void *item);
void    *Stack_top(Stack_T s);
void    Stack_pop(Stack_T s);
int     Stack_isEmpty(Stack_T s);
```


Generic Data Structures via void*

- Problem: Client must know what type of data a void pointer is pointing to

```
/* client.c */

int *i;
…
Stack_T s;
s = Stack_new();
Stack_push(s, "hello");
…
i = Stack_top(s);
```

Client pushes a string

Client considers retrieved value to be a pointer to an int! Legal!!! Trouble!!!

- Solution: None
  - Void pointers subvert the compiler's type checking
  - Programmer's responsibility to avoid type mismatches

Generic Data Structures via void*

- Problem: Stack items must be pointers
  - E.g. Stack items cannot be of primitive types (int, double, etc.)

```
/* client.c */
…
int i = 5;
…
Stack_T s;
s = Stack_new();
…
Stack_push(s, 5);
…
Stack_push(s, &i);
```

Not OK to match an actual parameter of type int with a formal parameter of type void*

OK, but awkward

- Solution: none
  - In C, there is no mechanism to create truly generic data structures
  - (In C++: Use template classes and template functions)
  - (In Java: Use generic classes)

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Generic Algorithms Example

- Suppose we wish to add another function to the Stack module

```
/* stack.h */

typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void    Stack_free(Stack_T s);
void    Stack_push(Stack_T s, const void *item);
void   *Stack_top(Stack_T s);
void    Stack_pop(Stack_T s);
int     Stack_isEmpty(Stack_T s);
int     Stack_areEqual(Stack_T s1, Stack_T s2);
```

Returns 1 (TRUE) iff s1 and s2 are equal, that is, contain equal items in the same order

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Generic Algorithm Attempt 1

- Attempt 1

```
/* stack.c */

…

int Stack_areEqual(Stack_T s1, Stack_T s2) {
   return s1 == s2;
}
```

```
/* client.c */

char str1[] = "hi";
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1,s2)) {
   …
}
```

Returns 0 (FALSE)
Incorrect!

- Checks if s1 and s2 are ***identical***, not ***equal***
  - Compares pointers, not items
- That's not what we want

Addresses vs. Values

- Suppose two locations in memory have the same value

```
int i=5;
int j=5;
```

i	5
j	5

- The addresses of the variables are *not* the same
  - That is "(&i == &j)" is FALSE
- Need to compare the values themselves
  - That is "(i == j)" is TRUE
- Unfortunately, comparison operation is type specific
  - The "==" works for integers and floating-point numbers
  - But not for strings and more complex data structures

Generic Algorithm Attempt 2

- Attempt 2

```
/* stack.c */
…
int Stack_areEqual(Stack_T s1, Stack_T s2) {
   struct Node *p1 = s1->first;
   struct Node *p2 = s2->first;
   while ((p1 != NULL) && (p2 != NULL)) {
      if (p1 != p2)
         return 0;
      p1 = p1->next;
      p2 = p2->next;
   }
   if ((p1 != NULL) || (p2 != NULL))
      return 0;
   return 1;
}
```

```
/* client.c */

char str1[] = "hi";
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1,s2)) {
   …
}
```

Returns 0 (FALSE)
Incorrect!

- Checks if ***nodes*** are ***identical***
  - Compares pointers, not items
- That is *still* not what we want

Generic Algorithm Attempt 3

- Attempt 3

```
/* stack.c */
…
int Stack_areEqual(Stack_T s1, Stack_T s2) {
   struct Node *p1 = s1->first;
   struct Node *p2 = s2->first;
   while ((p1 != NULL) && (p2 != NULL)) {
      if (p1->item != p2->item)
         return 0;
      p1 = p1->next;
      p2 = p2->next;
   }
   if ((p1 != NULL) || (p2 != NULL))
      return 0;
   return 1;
}
```

```
/* client.c */

char str1[] = "hi";
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1,s2)) {
   …
}
```

Returns 0 (FALSE)
Incorrect!

- Checks if ***items*** are ***identical***
  - Compares pointers to items, not items themselves
- That is *still* not what we want

Generic Algorithm Attempt 4

- Attempt 4

```
/* stack.c */
…
int Stack_areEqual(Stack_T s1, Stack_T s2) {
   struct Node *p1 = s1->first;
   struct Node *p2 = s2->first;
   while ((p1 != NULL) && (p2 != NULL)) {
      if (strcmp(p1->item, p2->item) != 0)
         return 0;
      p1 = p1->next;
      p2 = p2->next;
   }
   if ((p1 != NULL) || (p2 != NULL))
      return 0;
   return 1;
}
```

```
/* client.c */

char str1[] = "hi";
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1,s2)) {
   …
}
```

Returns 1 (TRUE)
Correct!

- Checks if ***items*** are ***equal***
- That's what we want
- But **`strcmp()`** works only if items are strings! We need **`Stack_areEqual()`** to be ***generic***
- How to compare values when we don't know their type?

Generic Algorithm via Function Pointer

- Approach 5

```
/* stack.h */

typedef struct Stack *Stack_T;

Stack_T Stack_new(void);
void    Stack_free(Stack_T s);
void    Stack_push(Stack_T s, const void *item);
void   *Stack_top(Stack_T s);
void    Stack_pop(Stack_T s);
int     Stack_isEmpty(Stack_T s);
int     Stack_areEqual(Stack_T s1, Stack_T s2,
           int (*cmp)(const void *item1, const void *item2));
```

- Add parameter to **`Stack_areEqual()`**
  - Pointer to a compare function, which…
  - Accepts two const void * parameters, and…
  - Returns an int
- Allows client to supply the function that **`Stack_areEqual()`** should call to compare items

Generic Algorithm via Function Pointer

- Approach 5 (cont.)

```
/* stack.c */
…
int Stack_areEqual(Stack_T s1, Stack_T s2,
   int (*cmp)(const void *item1, const void *item2)) {
   struct Node *p1 = s1->first;
   struct Node *p2 = s2->first;
   while ((p1 != NULL) && (p2 != NULL)) {
      if ((*cmp)(p1->item, p2->item) != 0)
         return 0;
      p1 = p1->next;
      p2 = p2->next;
   }
   if ((p1 != NULL) || (p2 != NULL))
      return 0;
   return 1;
}
```

- Definition of **`Stack_areEqual()`** uses the function pointer to call the client-supplied compare function
- **`Stack_areEqual()`** "calls back" into client code

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Generic Algorithm via Function Pointer

- Approach 5 (cont.)

```
/* client.c */

int strCompare(const void *item1, const void *item2) {
   char *str1 = item1;
   char *str2 = item2;
   return strcmp(str1, str2);
}
…
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1,s2,strCompare)) {
   …
}
```

Returns 1 (TRUE)
Correct!

Client passes address of **`strCompare()`** to **`Stack_areEqual()`**

- Client defines "callback function", and passes pointer to it to **`Stack_areEqual()`**
- Callback function must match **`Stack_areEqual()`** parameter exactly

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Generic Algorithm via Function Pointer

- Alternative: Client defines more "natural" callback function, and casts it to match **`Stack_areEqual()`** parameter
- Approach 5 (cont.)

```
/* client.c */

int strCompare(const char *str1, const char *str2) {
   return strcmp(str1, str2);
}
…
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1, s2,
   (int (*)(const void*, const void*))strCompare)) {
   …
}
```

Cast operator

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Generic Algorithm via Function Pointer

- Approach 5 (cont.)

```
/* client.c */
…
char str2[] = "hi";
Stack_T s1 = Stack_new();
Stack_T s2 = Stack_new();
Stack_push(s1, str1);
Stack_push(s2, str2);

if (Stack_areEqual(s1, s2,
   (int (*)(const void*, const void*))strcmp)) {
   …
}
```

Cast operator

- Alternative (for string comparisons only): Simply use **`strcmp()`** with cast!

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SymTable Aside

- Consider SymTable (from Assignment 3)…
- Q: Should a SymTable object own its values?
- A: No.
  - The SymTable module is generic with respect to values
  - So a SymTable object does not know the types of its values
  - So it ***cannot*** create copies of them (unless the client supplies a "copy" function)
  - So (by the "Resources" heuristic from the Modularity lecture) it should not free them

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Summary

- Generic data structures
  - Via item typedef
    - Safe, but not realistic
  - Via the generic pointer (void*)
    - Limiting: items must be pointers
    - Dangerous: subverts compiler type checking
    - The best we can do in C
      - (See C++ template classes and Java generics for other approaches)
- Generic algorithms
  - Via function pointers and callback functions

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Appendix: Wrappers

- Can we make void * functions safer?

```
/* hotel.h */

Typedef struct Room Room;

void    RoomStack_push(Stack_T s, const Room *item);
Room   *RoomStack_top(Stack_T s);
int     RoomStack_areEqual(Stack_T s1, Stack_T s2);
```

```
/* hotel.c */

void    RoomStack_push(Stack_T s, const Room *item) {
         Stack_push(s, item);
}
Room   *RoomStack_top(Stack_T s){
         return Stack_top(s);
}
int     RoomStack_areEqual(Stack_T s1, Stack_T s2) {
         return Stack_areEqual(s1, s2, RoomCompare);
}
```

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Faster Wrappers

- Move it to the header
- Make it static and inline
- Let the compiler sort it out

```
/* hotel.h */

Typedef struct Room Room;

static inline void RoomStack_push(Stack_T s, const Room *item) {
         Stack_push(s, item);
}
static inline Room *RoomStack_top(Stack_T s) {
         return Stack_top(s);
}
static inline int RoomStack_areEqual(Stack_T s1, Stack_T s2) {
         return Stack_areEqual(s1, s2, RoomCompare);
}
```

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What About The Stack Itself?

- Previous approach only protected Room
  - Only rooms could be pushed
- Stack was not specific
  - Any valid stack could be provided to functions
  - Still possible to confuse stacks
  - Result: stacks of mixed types
  - Worse: gives impression that output always a Room
- Solution: typecast the stack

```
/* stack.h */

typedef struct Stack *Stack_T;
Typedef struct RoomStack *RoomStack_T

Stack_T Stack_new(void);
static inline RoomStack_T RoomStack_new(void) {
        return ((RoomStack_T) Stack_new());
}
```

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