



Generics

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Recall the Stack Module



```
/* stack.h */  
  
typedef struct Stack *Stack_T;  
  
Stack_T Stack_new(void);  
void Stack_free(Stack_T s);  
int 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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Recall the Stack Module



- Stacks and their operations (push, pop, top, etc.) make sense for items other than strings too
- Problem: How to make Stack module generic?

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Goals of this Lecture



- Help you learn about:
 - Generic data structures
 - Data structures that can store multiple types of data
 - Generic functions
 - 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?
 - Generic modules are more reusable than non-generic ones
 - Reusing old code is cheaper than writing new code
 - A power programmer knows how to **create** generic modules and how to **use** generic modules to create large programs

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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);  
int 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);
```

Do you see any problems with this approach? (Think before looking at next slide.)

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Generic Data Structures via typedef



- Problems
 - Awkward: Client must define structure type and create structures of that type
 - Limiting: Client might already use "Item_T" for some other purpose
 - Limiting: 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);
int 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);
int 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);  
int 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 *



- Problem: Client must know what type of data a void pointer is pointing to (void ptrs subvert compiler's type checking)

```
/* 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.
This is Legal.
And it's Trouble.

- Solution?

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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?

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Where that does leave us?



- Not in a great place
 - Generic data structures via item typedef
 - Safe, but not realistic
 - Generic data structures via the generic pointer (void *)
 - Limiting: items must be pointers
 - Dangerous: subverts compiler type checking
 - The best we can do in C

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What about Generic Algorithms?



- Suppose we want 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);  
int 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);
```

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

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Generic Algorithm 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)) {  
    ...  
}
```

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

What does this return?

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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
 - “(&i == &j)” is FALSE
- Need to compare the values themselves
 - “(i == j)” is TRUE
- Unfortunately, comparison operation is type specific
 - The “==” operator works for integers and floating-point numbers
 - But not for strings and more complex data structures
 - Can’t use it for all data types

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Generic Algorithm 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)) {
    ...
}
```

What does this return?

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

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Generic Algorithm 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)) {
    ...
}
```

What does this return?

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

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Generic Algorithm 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)) {
    ...
}
```

What does this return?

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

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Generic Algorithm via Function Pointer



• Attempt 5

```
/* stack.h */  
  
typedef struct Stack *Stack_T;  
  
Stack_T Stack_new(void);  
void Stack_free(Stack_T s);  
int 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()`
 - Generic pointer to a (compare) function
- Allows client to supply the function that `Stack_areEqual()` should call to compare items

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Generic Algorithm via Function Pointer



• Attempt 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



- Attempt 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) {
    ...
}
```

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

What does this return?

- 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
- Attempt 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)) {
    ...
}
```

What kind of construct is this?

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Generic Algorithm via Function Pointer



- Attempt 5 (cont.): Simplify further

```
/* 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) ) {
    ...
}
```

Again, what kind of construct is this?

- Alternative (for string comparisons only): Simply use `strcmp()`

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SymTable Aside



- Consider SymTable (from Assignment 3)...
- A SymTable object owns its keys
- A SymTable object does not own its values

Was that a good design decision? Should a SymTable object own its values?

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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
- **Generic algorithms**
 - Via function pointers and callback functions

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Appendix: Wrappers



- **Q:** Can we make “void pointer” generic ADTs safer?
- **A:** Yes, with some extra work...
- **Example: Suppose**
 - We have a generic **Stack** ADT
 - Items are void pointers
 - We wish to create a **StrStack** ADT
 - Same as **Stack**, except items are strings (char pointers)

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Appendix: Wrapper Interface



- Define type-specific interface

```
/* strstack.h */
...
typedef struct StrStack *StrStack_T;

StrStack_T StrStack_new(void);
void StrStack_free(StrStack_T ss);
int StrStack_push(StrStack_T ss, const char *item);
char *StrStack_top(StrStack_T ss);
void StrStack_pop(StrStack_T ss);
int StrStack_isEmpty(StrStack_T ss);
...
```

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Appendix: Wrapper Data Structure



- Define StrStack structure such that it has one field of type Stack_T

```
/* strstack.c */

struct StrStack {
    Stack_T s;
};

...
```

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Appendix: Wrapper Functions



- Define `StrStack_new()` to call `Stack_new()`

```
/* strstack.c */
...
StrStack_T StrStack_new(void) {
    Stack_T s;
    StrStack_T ss;
    s = Stack_new();
    if (s == NULL)
        return NULL;
    ss = (StrStack_T)malloc(sizeof(struct StrStack));
    if (ss == NULL) {
        Stack_free(s);
        return NULL;
    }
    ss->s = s;
    return ss;
}
...
```

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Appendix: Wrapper Functions



- Define `StrStack_free()` to call `Stack_free()`

```
/* strstack.c */
...
void StrStack_free(StrStack_T ss) {
    Stack_free(ss->s);
    free(ss);
}
...
```

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Appendix: Wrapper Functions



- Define remaining StrStack functions to call corresponding Stack functions, with casts

```
/* strstack.c */
...
int StrStack_push(StrStack_T ss, const char *item) {
    return Stack_push(ss->s, (const void*)item);
}
char *StrStack_top(StrStack_T ss) {
    return (char*)Stack_top(ss->s);
}
void StrStack_pop(StrStack_T ss) {
    Stack_pop(ss->s);
}
int StrStack_isEmpty(StrStack_T ss) {
    return Stack_isEmpty(ss->s);
}
int StrStack_areEqual(StrStack_T ss1, StrStack_T ss2) {
    return Stack_areEqual(ss1->s, ss2->s,
        (int (*)(const void*, const void*))strcmp);
}
...
```

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Appendix: The Wrapper Concept



- StrStack is a **wrapper** ADT
 - A StrStack object “wraps around” a Stack object
- A wrapper object
 - Does little work
 - Delegates (almost) all work to the wrapped object
- Pros and cons of the wrapper concept
 - (+) **Type safety**: (As StrStack illustrates) wrapper can be designed to provide type safety
 - (+) **Client convenience**: (More generally) wrapper tailors generic ADT to needs of specific client
 - (-) **Developer inconvenience**: Must develop/maintain distinct wrapper for each distinct client need

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