Generics (Γενικότητα)

Μπορούμε να κατασκευάσουμε ΑΤΔ που επιτρέπει χρήση με διαφορετικούς Τύπους Δεδομένων στο ίδιο πρόγραμμα;

Π.χ. Μια στοίβα με char* και μια με int

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

- Stack

```
/* 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*)

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***?

Generic Data Structures via typedef

- Solution 1: Let clients define item type (G2)

```
/* 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);
```

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…

Generic Data Structures via void*

- Solution 2: The generic pointer (void*) (G3)

```
/* 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*

- 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*

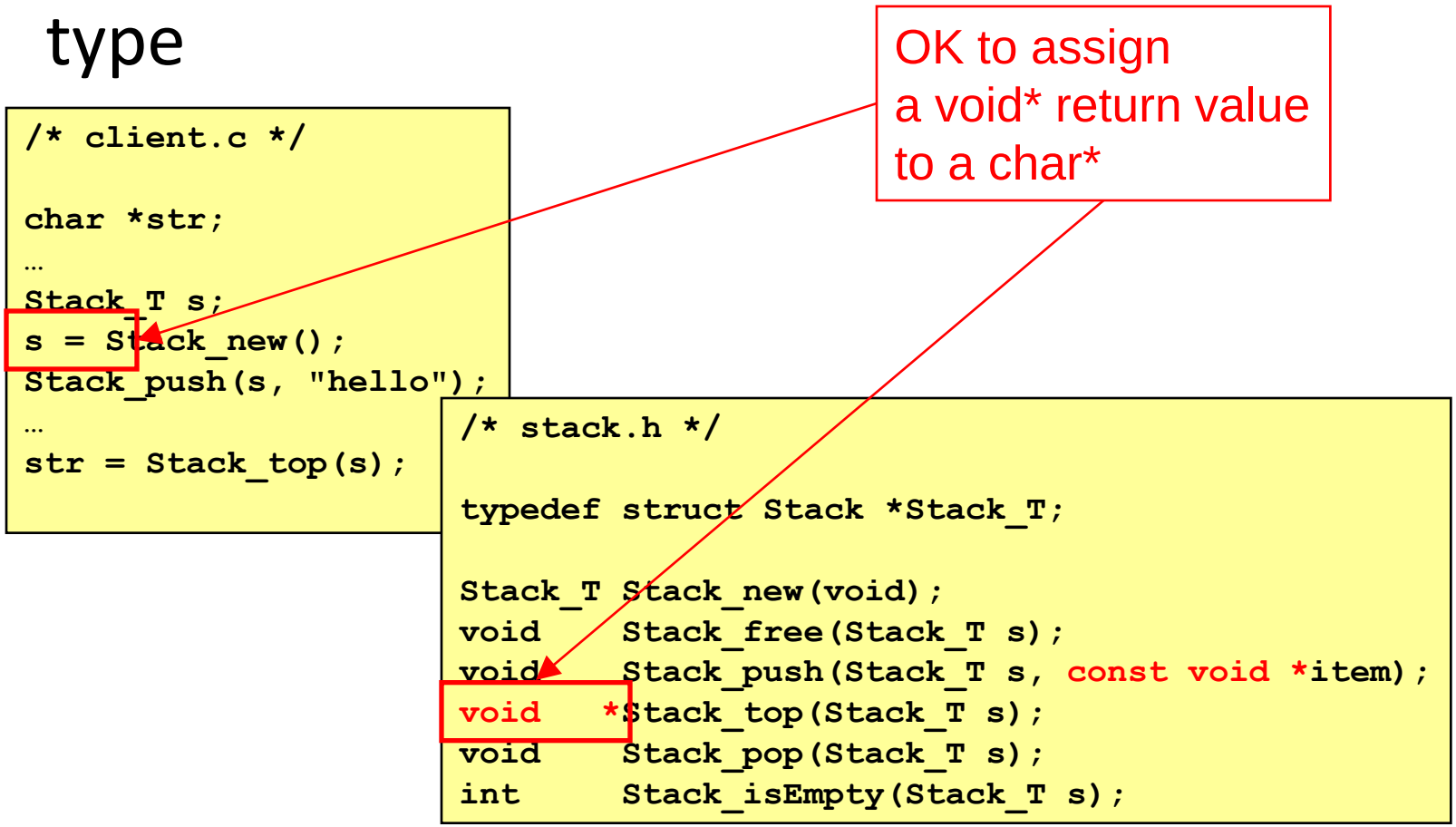
```
/* stack.h */

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);
```

Generic Data Structures via void*

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



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)

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

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)) {
   …
}
```

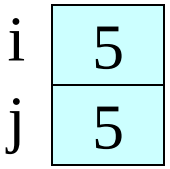
Returns 0 (FALSE)
Incorrect!

  - 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;
```



- 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)) {
   …
}
```

  - 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?

Returns 1 (TRUE)
Correct!

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

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

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

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!

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

Genericity	Modularity					
	No Modularity	Απόκρυψη Πράξεων (MA)	Απόκρυψη Δεδομένων Πράξεων (OA)	+	-
TS στον κώδικα	Demo Mod 0	Demo Mod 1	Demo Mod 3+2	έλεγχος μεταγλώττισης	Νέο ΤΣ απαιτεί Αλλαγή Υλοποίησης
TS MA σε .h +. c		ΝΑΙ με Προσοχή 1η άσκηση	ΝΑΙ 2η άσκηση	Αλλαγή ΤΣ δεν απαιτεί αλλαγή υλοποίησης ΑΤΔ, έλεγχος μεταγλώττισης	1 μόνο ΤΣ, Αλλαγή ΤΑ απαιτεί recompilation
ΤΣ (OA) * TS		Χωρίς ιδιαίτερο όφελος	ΝΑΙ, απαιτεί καλή χρήση δεικτών	Αλλαγή ΤΣ δεν απαιτεί αλλαγή υλοποίησης ΑΤΔ, δεν απαιτεί recompilation, έλεγχος μεταγλώττισης	1 μόνο ΤΣ
ΤΣ (OA) * void		Χωρίς ιδιαίτερο όφελος	απαιτεί καλούς ελέγχους	πολλά-ΤΣ, σταθερή υλοποίηση ΑΤΔ, δεν απαιτεί recompilation	χωρίς έλεγχο μεταγλώττισης
+		προσοχή στην άμεση χρήση στον Τύπο.	Η καλύτερη απόκρυψη		
-		Κίνδυνοι αλλοίωση απόκρυψης	δείκτες και όχι structs		

1 ΤΣ μπορεί να καλύπτει πολλούς τύπους με union