Other Features of Procedures

- overloading
  - multiple procedures with same name
  - must differ in signature
    - result type part of signature?
- overriding
  - same signature
  - may still be able to access original method
- default parameters
  - can omit actual parameters
  - must be last parameters

```
procedure inc (item: in out integer; by: in integer := 1;
               mul: in integer :=1) is
begin
  item := item*mul+by;
end inc;
  :
inc(i);
```

- named parameters
  - parameter association by name rather than position

```
inc(by=>2,mul=>3,item=>i);
inc(i,mul=>3);
```

Functions

- procedures which return a value
  - differentiation, e.g. none in C, ALGOL 60
- specifying result
  - assignment to function name vs return statement
- result can be considered extra result parameter
- return type
  - simple type – ALGOL 60, Java, Pascal
    - but also references
  - structured type – Ada, C, C++, FORTRAN 90, Algol 68
- order of evaluation
  - partial ordering
    - efficient code generation
  - side effects
- modifying parameters?!? For shame!
  - side effects
  - Ada, C++ `const`

Examples

- Fortran 90

```
FUNCTION TWICE(A)
  INTEGER TWICE
  INTEGER A
  TWICE = A + A
END FUNCTION TWICE
```

- Algol 60

```
integer procedure twice(a);
  value a; integer a;
  twice := a + a
```

- C++

```
int twice(int a) const {
  return a + a;
}// twice
```

- Java

```
int twice(int a) {
  return a + a;
}// twice
```

- Pascal

```
function twice(a : Integer):Integer;
begin
  twice := a + a
end; {twice}
```

- Ada

```
function twice(a : in Integer)
                  return Integer is
begin
  return a + a;
end twice;
```

Operators

- operators use infix, functions use prefix
- functions define new operations
- declaring new operators
  - really functions with different syntax

```
function "+"(today : in Day; n : in Integer) return Day is
begin
   return Day'val((Day'pos(today) + n) rem 7);
end;
```

  - choice of operator
    - existing operator symbols
    - other symbols
  - precedence rules

Storage Management

- storage for local variables
- static
  - pre-allocation - load-time (declaration-reference) binding
    - efficient access
  - size of each item known at compile time
  - no data item has multiple simultaneous occurrences

    $\Rightarrow$ no recursion
  - FORTRAN
  - interesting notes:
    - since memory is pre-allocated, it's always being reserved, even when not in use
    - if a function is revisited, the old values may still be there

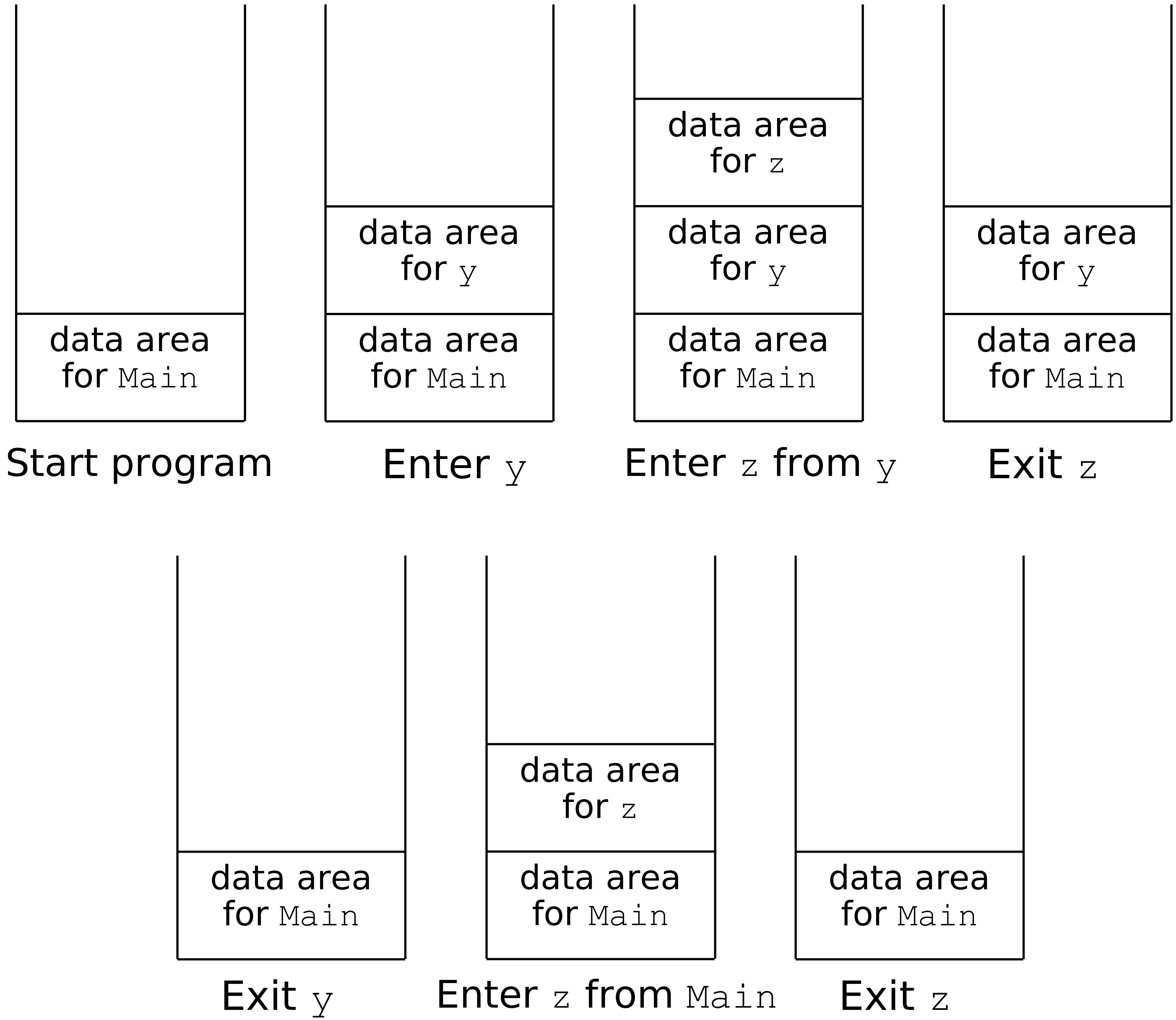
- stack-based
  - block-structured languages
  - binding at block entry/de-allocation at exit
    - stack of activation records (AR); run-time stack
  - storage only for locals of active methods
  - **addresses as offsets**
    - hardware support
  - *Ask me about return values*

```
program Main(output);
   var b, d : Integer;

   procedure z;
       var e, f : Integer;
   begin
       …
   end {z};

   procedure y;
       var g, h : Integer;
   begin
       …z; …
   end {y};

begin
   …y;
   … z; …
end.
```


data area
for Main
Start program
data area
for y
data area
for Main
Enter y
data area
for z
data area
for y
data area
for Main
Enter z from y
data area
for y
data area
for Main
Exit z
data area
for Main
Exit y
data area
for z
data area
for Main
Enter z from Main
data area
for Main
Exit z

Activation Records

- local variables & **parameters**
- system information
  - return address
  - restore stack?
  - dynamic chain
- access
  - non-locals (inherited) not at fixed place
    - different calls give different stack structure
  - static chain
    - access is distance up chain plus offset

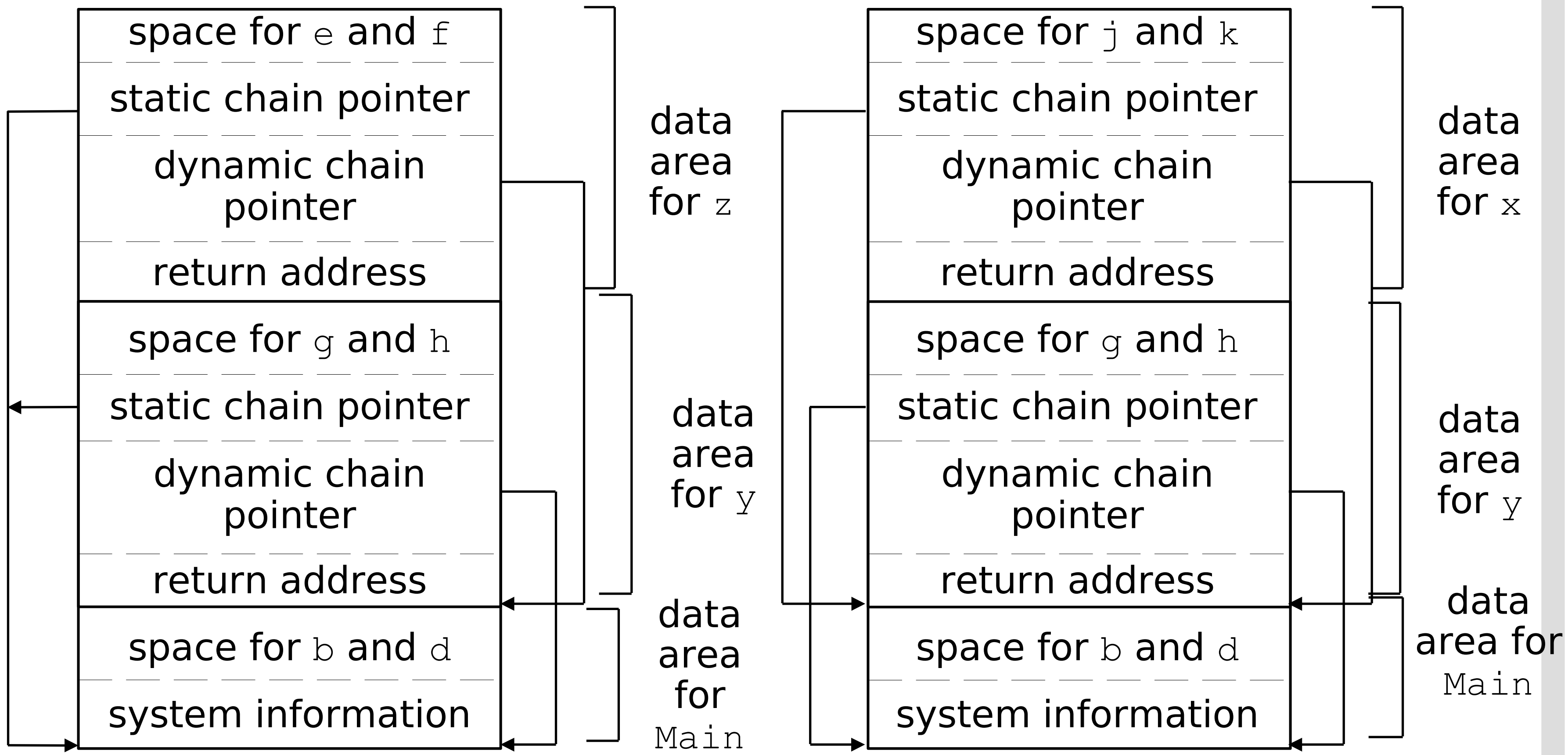
```
program Main(output);
   var b, d : Integer;

   procedure z;
       var e, f : Integer;
   begin
       …
   end {z};

   procedure y;
       var g, h : Integer;
       procedure x;
    var j, k : Integer;
       begin
    …
       end {x};
   begin
       …z; …x; …
   end {y};

begin
   …z; …y; …
end.
```

Run-Time stack



when z has been called from y

when x has been called from y

Activation Records

- recursion
  - stack-based supports recursion
    - each invocation has its own storage
  - multiple ARs for different invocations of same procedure

```
int factorial(int n) {
  if (n > 1)
      return n * factorial(n - 1);
  else
      return 1;
}// factorial
```

Activation Records

```
   factorial(3)
→ 3 * factorial(2)
→ 3 * 2 * factorial(1)
→ 3 * 2 * 1
```

data area for the call
`factorial(1)`

data area for the call
`factorial(2)`

data area for the call
`factorial(3)`

data area for the main program

Forward References

- Pascal
  - one-pass compiler
  - defined before use
    - scope sometimes extends from declaration to the end of the block; not starting at beginning of block
  - mutually-recursive procedures?
  - forward reference
    - signature without body

```
procedure operand(var ca : Character); forward;

procedure exp( var cb : Character);
begin
   operand(cb);
   while cb = '+' do
       operand(cb)
end {exp};

procedure operand(var ca : Character);
begin
   read(ca);
   if ca = '(' then
   begin
       exp(ca);
       if ca <> ')' then writeln("missing brackets")
   end else
   if ca <> 'a' then writeln("missing operand");
   read(ca)
end {operand};
```

Forward References

- function prototypes in C & C++

```
void operand(char *);
```

- function specification vs function body in Ada

```
function a(b : Integer) return Real;

function a(b : Integer) return Real is
begin … end a;
```

- ALGOL 60, Algol 68 & Java don’t require defined before use
  - compiler must do multiple passes

Subprogram as Parameters

- functions and procedures passed as parameters
  - basic principle in functional languages
  - less widely used in imperative languages
- specification of function parameters
  - types of their parameters?

```
function slope(f(y : Real) : Real; x1, x2 :
Real) : Real;
begin
    if x1 = x2
  then slope := 0
      else slope := (f(x2) - f(x1)) / (x2 - x1)
end {slope};
```

```
function straight(x : Real) :
   Real;
begin
   straight := 2 * x + 1
end {straight};

function tan(x : Real) : Real;
begin
   tan := sin(x) / cos(x)
end {tan};

slope(straight, 3.8, 3.83);
slope(tan, 3.8, 3.85);
```

Subprogram as Parameters

- procedure types and procedure variables
  - e.g. Modula-2

```
TYPE realfunc = PROCEDURE(REAL) : REAL;

var fx : realfunc;
fx := straight;

PROCEDURE slope(f : realfunc; x1, x2 : REAL) : REAL;
BEGIN
    IF x1 = x2 THEN
   RETURN 0
    ELSE
   RETURN (f(x2) - f(x1)) / (x2 - x1)
    END
END slope;
```

- generics in Ada
  - compile-time parameters
  - generic instantiation
    - creates distinct functions

```
generic
    with function f(y: Real) return Real;
function slope(x1, x2 : Real) return Real;

function slope(x1, x2 : Real) return Real is
begin
    if x1 = x2 then
   return 0;
    else
   return (f(x2) - f(x1)) / (x2 - x1);
end slope;

function straight_slope is new slope(f => straight);
function tan_slope is new slope(f => tan);
```

Structured Data

- data structures
  - components
- arrays
  - features
- records (structures)
  - features
- dynamic data structures
  - linked structures
  - pointers and dynamic storage allocation

Arrays

- attributes
  - element type
  - dimensionality
    - bounds
    - subscript type
  - Pascal

```
type Matrix = array [1 .. 10, 0 .. 15] of Real;
var a : Matrix;
```

- computable index
  - bounds error
    - Pascal → run-time error
    - Ada & Java → exception thrown
    - C & C++ →access to some location outside the array
  - notation `()` vs `[]`

- multi-dimensional array vs array of arrays

```
type Row = array [0 .. 15] of Real;
type Matrix = array [1 .. 10] of Row;
var b : Matrix;
```

`a[2,3]` vs `b[2][3]`

- Java
  - 0 lower bound
  - arrays are “objects”
  - multi-dimensional uses array-of-array model

Access to Elements

- efficient implementation
- mapping function
  - contiguous allocation
  - row-major vs column major
  - contiguous allocation: `a[i,j]`

```
base_address + component_size *
  (row_length * (i - first_lower_bound)
              + j - second_lower_bound)
```

- access via pointers (C, C++)
  - array name as pointer constant
  - pointer increment
  - dangling pointer
  - parameter passing
    - array name is reference to array

```
double arow[16];
```

```
double total = 0.0;
for (int i = 0; i < 16; i++)
   total += arow[i];
```

```
double total = 0.0;
double *b;
b = arow;
for (int i = 0; i < 16; i++)
   total += *b++;
```

Name-Size Binding

- static arrays
  - bounds constant at compile time
  - efficient implementation
  - arrays of max size – waste space
- semi-dynamic arrays
  - bounds evaluated at block entry
  - implement as pointer to storage allocated on top of stack
  - slightly less efficient (extra dereference)

```
type Matrix is array(Integer range <>,
                     Integer range <>) of Real;

a, b : Matrix(1 .. m, 1 .. n);
```

- dynamic arrays
  - bounds evaluated at statement execution
  - variable may reference arrays of different size (different arrays)

```
double[] arow = new double[16];

arow = new double[20];
```

- extensible arrays
  - bounds of same array may change at execution (extension)
  - expensive implementation

Arrays as Parameters

- bounds as part of type specification
  - Pascal
  - different bounds?

```
type List = array[1 .. 20] of Real;

function sum(a : List) : Real;
var i : Integer;
  total : Real;
begin
  total := 0.0;
  for i := 1 to 20 do
   total := total + a[i];
  sum := total;
end {sum};
```

- conformant array parameters
  - bounds as implicit parameters
  - var parameters
  - value parameters – space allocation

```
function sum(a : array[low .. high : Integer] of Real) :
                                                    Real;
var i : Integer;
  total : Real;
begin
  total := 0.0;
  for i := low to high do
   total := total + a[i];
  sum := total;
end {sum};
```

- unconstrained arrays
  - Ada
  - array attributes

```
type List is array(Integer range <>) of Real;

function sum(a : List) return Real is
  total : Real := 0.0;
begin
  for i in a'range loop
    total := total + a(i);
  end loop;
  return total;
end sum;
```

- arrays as objects
  - Java
  - `length` attribute

- array parameters as pointers (C, C++)
  - pass attributes as extra parameters

```
double sum ( const double a[], int length );
```

or

```
double sum ( const double* a, int length );
```

- parameter conformance
  - structural equivalence vs name equivalence

```
type First = array[1..10] of Integer;
     Second = array[1..10] of Integer;
var a : First;
    b : Second;
    c : array [1..10] of Integer;
    d, e : array[1..10] of Integer;
    f : First;
```

  - Pascal & Ada (name) vs C++ & Java (structural)

Arrays – Misc.

- aggregates
  - array literals or constructors

```
type Vector is array (1 .. 6) of Integer;
a : Vector;
a := (7, 0, 7, 0, 0, 0);
```

Ada

```
int a[] = {7, 0, 7, 0, 0, 0};
int a[6] = {7, 0, 7};
```

C++

```
int[] a = {7, 0, 7, 0, 0, 0};
```

Java

- slices
  - subsections of an array
  - array-of-array – row slices
  - general slices

```
a(1 .. 3) := b(4 .. 6);
```

- array operators
  - PL/I and APL

- arrays as function results
  - also operator overloading

```
function add(left, right : Vector) return Vector is
  total : Vector;
begin
  for i in left'range loop
     total[i] := left[i] + right[i];
  end loop;
  return total;
end add;

c := add(a, b);         c := a + b;
```

- associative arrays
  - any value as index
  - key – data mapping (`Map` in Java)
  - implementation as hashtables

```
Hashtable<String,PeopleInfo> persons
             = new Hashtable <String,PeopleInfo>();
PeopleInfo p1, p2, p3;
…code to give a value to p1, p2 and p3…
persons.put(“J Smith”, p1);
persons.put(“F Bloggs”, p2);
persons.put(“A Brown”, p3);

PeopleInfo inf = persons.get(“F Bloggs”);
```

Records & Classes

- record
  - non-homogeneous collection
  - components (fields) accessed by name
  - originally for file processing (COBOL)
  - later for data organization
    - Pascal, C, C++
  - C++
    - both data and function members
    - associate operations with data
- classes
  - derived from records
  - C++ `class` is same as `struct`
  - classes without methods - records
  - classes without instance variables - method libraries

Stack Example (Pascal)

- record type for `CharStack`
- methods taking `CharStack` parameter
- dot notation for field access
- no grouping or encapsulation

```
type CharStack =
   record
    val : array [1 .. 20] of Char;
    head : 0 .. 20;
   end;

var a, b : CharStack;
    ch : Char;
```

```
procedure initialise(var stack : CharStack);
begin
   stack.head := 0;
end; {initialise}

function isEmpty(stack : CharStack) : Boolean;
begin
   isEmpty := stack.head = 0;
end; {isEmpty}

procedure push(var stack : CharStack; x : Char);
begin
   if stack.head = 20 then
      writeln('Error: stack full');
   else
   begin
      stack.head := stack.head + 1;
      stack.val[stack.head] := x;
   end;
end; {push}
```

```
procedure pop(var stack : CharStack; var x : Char);
begin
  if isEmpty(stack) then
     writeln('Error: stack empty');
  else
  begin
     x := stack.val[stack.head];
     stack.head := stack.head - 1;
  end;
end; {pop}
```

```
initialise(a); initialise(b);
push(a, 'f'); push(b, 'g');
pop(a, ch);
```

Stack Example (Ada)

- group record type and methods in a package
- `pop` cannot be function (only `in` parameters)
- control visibility
  - `private` types
    - `:=` and `=`
  - `limited private` types
    - no operations
- can change representation

```
package Stacks is
   type CharStack is limited private;
   procedure push(st : in out CharStack; x : in Character);
   procedure pop(st : in out CharStack; x : out Character);
   function isEmpty(st : CharStack) return Boolean;
private
   type Values is array(1 .. 20) of Character;
   type CharStack is
    record
        val : Values;
        head : Integer range 0 .. 20 := 0;
    end record;
end Stacks;
```

Stack Example (C++)

- data members for representation
- member functions for operations
  - method bodies separate
- arbitrarily sized stack
  - constructor
  - destructor

```
class CharStack {
   char *val;
   int head;
   int maxSize;
public:
   CharStack(int size);
   ~CharStack() {delete val;}
   void push(char x);
   char pop();
   int isEmpty() const;
};

CharStack :: CharStack(int size) {
  val = new char[size];
  head = -1;
  maxSize = size;
} // constructor

CharStack a(50), b(100);
```

Stack Example (Java)

- similar to C++
- garbage collection - no need for destructor

```
public class CharStack {
   private char[]   val;
   private int   head;
   public CharStack ( int size ) {
   elts = new char[size];
   head = -1;
   };  // constructor
   public void push ( char x ) { … }; // push
   public char pop ( ) { … }; // pop
   public boolean isEmpty ( ) { … }; // empty
}  // CharStack
```

Variant Records

- static typing is inflexible
  - e.g. class list with undergrad and grad students
  - cannot use array since must be homogeneous
- Pascal & Ada - variant records
  - fixed part
  - variant part
  - discriminant (tag field)
  - single type
  - access to variants
  - modification of discriminant
- object-oriented languages
  - replaced by inheritance and polymorphism

```
type Status = (undergraduate, postgraduate);
     Student =
       record {fixed part}
         name : String;
         case kind : Status of {variant part}
         undergraduate : (advisor : String);
         postgraduate  : (course : String;
        supervisor : String)
       end;

var studentlist : array[1..3000] of Student;

write(studentlist[i].name);
if studentlist[i].kind = undergraduate then
  writeln(studentlist[i].advisor);
else
   writeln(studentlist[i].course,
          studentlist[i].supervisor);
```

Dynamic Data Structures

- nodes linked together by pointers
- nodes - records/classes
- dynamic allocation
- Pascal
  - record structure
  - pointer type
  - procedures

```
type Ptr = ^Node;
  Node =
    record
      data : Char;
      next : Ptr;
    end;


procedure add(c : Char; var head : Ptr);
var p : Ptr;
begin
   new(p); p^.data := c;
   p^.next := head;
   head := p;
end; {add}
```

- Ada
  - package for association and visibility
  - initialization at creation
- C
  - self-referential type

```
struct Node {
  char data;
  struct Node *next;
}
```

  - similar to Pascal
- Java
  - no pointers but object variables are references
  - package visibility (class not `public`) makes `Node` visible to `List` but not outside package

```
class Node {
   char data;
   Node next;
   public Node(char c, Node p) {
    data = c; next = p;
   }// constructor
}// Node

class List {
   private Node head;
   public List() {
    head = null;
   }// constructor
   public void add(char c) {
    head = new Node(c, head);
   }// add
   …
}// List
```

- C++
  - similar to Java
  - requires pointers
  - friend class

```
class Node {
  …
  friend class List;
  …
}
```

    - `List` can access private members

Parametric Types

- e.g. stack - code same regardless of component type
- type as a parameter to another type
  - e.g. array of `int`, stack of `char`
- Ada
  - generic package
    - type (and other things) as parameter to package
    - generic instantiation
      - compile-time
      - defines a new package
- C++
  - class templates similar to Ada generics
  - automatic generic instantiation

```
generic
   type Item is private;
   size : Integer;
package Stacks is
   type Stacks is limited private;
   procedure push(st : in out Stack; x : in Item);
   procedure pop(st : in out Stack; x : out Item);
   function isEmpty(st : Stack) return Boolean;
   private
      type Values is array(1 .. size) of Item;
      …
end Stacks;



package StkChar is new Stack(Item => Character, size => 20);
package StkInt is new Stack(Item => Integer, size => 20);
```

- Java
  - generics added in 1.5
  - doesn’t do generic instantiation, all variants are the same class

```
public class Stack <E> {
  private E[]   val;
  private int   head;
  public Stack ( int size ) {
  val = (E[])new Object[size];
  head = -1;
  };  // constructor
  public void push ( E item ) { … }; // push
  public E pop ( ) { … }; // pop
  public boolean isEmpty ( ) { … }; // empty
} // Stack

Stack<Character> s;
Character c;
s = new Stack<Character>(100);
s.push(c);
```

Strings

- Pascal, Ada
  - as arrays of char
  - fixed length representation
  - only operations that don’t change length
- C, C++
  - arrays of character
  - fixed length representation
  - may vary up to defined length
  - string terminator character

- Java
  - `String` as library type
    - immutable
  - `StringBuffer`
    - more efficient processing if length to change
    - essentially extensible varying length string
- pattern matching
  - SNOBOL
  - Perl - regular expressions
- implementation
  - contiguous sequence of char→array
  - varying length?
    - move when must extend
    - use linked structure
    - combination

Sets

- Pascal
  - set of discrete type
  - set operations
    - inclusion (presence), add, remove
  - representation is bitset
- bit strings
  - bit-level operations
  - C, C++, Java - `int` values
  - Ada - `Boolean` arrays

Files

- files on secondary storage
  - external to program
- Pascal
  - file type
    - sequence of values of some type
    - sequential access
    - EOF
    - can have file of record type
    - local vs external files
- usually files are considered external and supported by I/O facility