תכנות מתקדם ושפת C++
מצגת 5

בניית מחלקה

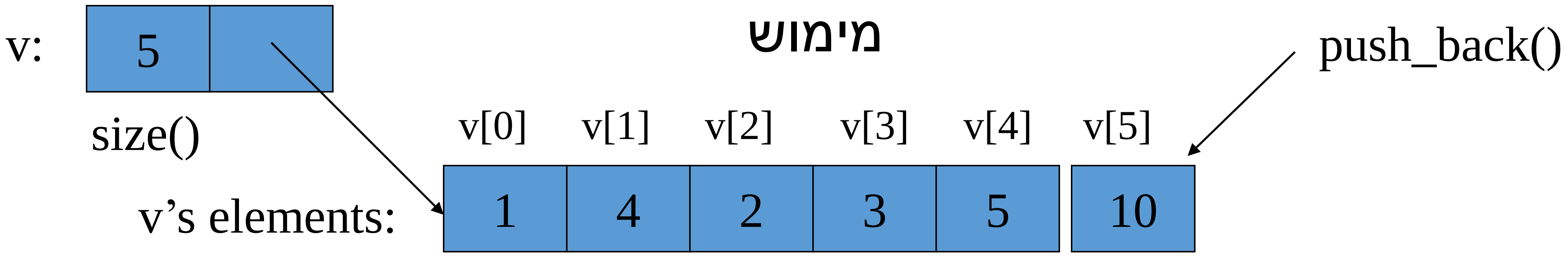
מחלקה

- מחלקה היא הרחבה של struct שבשפת C
  במחלקה ניתן להגדיר בנוסף למשתנים (Member Data)
  גם פונקציות חברות (Member Functions)
- **מחלקה מאפשרת:**
- **הפשטת נתונים (Data Abstraction)** התעלמות מפרטי המימוש של העצם והתרכזות במאפיינים שלו
- **כימוס (Encapsulation)** הסתרת פרטי המימוש מהמשתמש
  ניתן לקבוע הרשאות גישה לחברי המחלקה:
  חברי מחלקה המוגדרים private נגישים רק לפונקציות חברות במחלקה
  חברי מחלקה המוגדרים public נגישים גם לשאר פונקציות התכנית

בניית המחלקה וקטור

- וקטור הוא אחד המיכלים בספריה הסטנדרטית והשימושי ביותר.
- וקטור בדומה למערך המובנה בשפה מכיל סדרה של נתונים מאותו סוג, אך יש לו תכונות נוספות, אפשר להגדילו, להעתיקו, לדעת את גודלו.
- פעולות שכיחות בוקטור:

```
vector<int> v = {1,2,3,4,5} // initialize with a list
v[i] = 7;                   // access element i
v.push_back(10);            // add an element at end
```



מעבר על וקטור באמצעות אינדקס

```
int main() { // compute average temperatures
     vector<double> temps;
     double temp;
// cin >> temp returns a reference to cin
// if end of input it is converted to false
     while (cin >> temp) // idiom
          temps.push_back(temp);
     double sum = 0;
     for (int i = 0; i < temps.size(); ++i)
          sum += temps[i];
     cout << "Average: " << sum/temps.size() << '\n';
}
```

מעבר על וקטור עם הוספות של C++11

```
// use list initialization
vector<int> v = {10,20,30,40,50,60,70,80,90,100};
for (vector<int>::size_type i = 0; i != 5; ++i)
    cout << v[i] << " ";
// use range for to process all the elements
for (int i : v) cout << i << " ";
// let auto deduce the type of i
for (auto i : v) sum +=  i;
// use decltype instead of vector<int>::size_type
for (decltype(v.size()) i = 5; i != 10; ++i)
    cout << v[i] << " ";
```

מעבר על וקטור באמצעות איטרטור

```
vector<int> v = {10, 20, 30, 40, 50};

vector<int>::iterator iter = v.begin();
decltype(v.end()) end_iter = v.end();
while (iter != end_iter) {
    cout << *iter << endl;
    ++iter;
}

for (auto it = v.cbegin(); it != v.cend(); ++it)
    cout << *it << endl;
```

מימוש בסיסי של וקטור

```
class Vector {
    int sz;         // the size
    double* elem; // a pointer to the elements
public:
    using size_type = unsigned long;
    Vector(): sz{0}, elem{nullptr} {} //default constructor
    Vector(int s) // constructor with element count
        :sz{s}, elem{new double[s]} // initialize
        { for (int i = 0; i<sz; ++i) elem[i] = 0.0; }
    ~Vector()       // destructor
        { delete[] elem; }
    int size() { return sz; }};
Vector v1;      // use default constructor, not Vector v1();
Vector v2(10); // create a vector with 10 elements
```

nullptr

- We try to ensure that a pointer always points to an object, so that dereferencing it is valid
- When we don't have an object, we give the pointer the value `nullptr`
- In older code, **0** or **NULL** is typically used, but . . .

```
void func(int n);
void func(char *s);
func(NULL);         // which function is called? (int)
```

- using **nullptr** eliminates confusion between integers and pointers

```
func( nullptr ); // func(char *s) is called

double* pd = nullptr;
int x = nullptr; // error: nullptr is a pointer
```

בנאי ברירת מחדל (= default)

- If our class does not explicitly define any constructors, the compiler will implicitly define the default constructor for us
- It default-initializes the members
- Objects of **built-in** or compound type (such as arrays and pointers) that are defined inside a block have **undefined** value
- we can ask the compiler to generate the default constructor for us by writing **= default**

```
class Vector {
    Vector() = default;
```

- We are defining this constructor only because we want to provide other constructors

בנאי שמבצע המרה

- A constructor that takes a **single** argument defines a **conversion** from its argument type to its class, for example:

```
class complex {
   complex(double,double);
   complex(double); // defines double-to-complex
                    // conversion
   // . . .
};
complex z = complex{1.2,3.4};
z = 5.6;               // OK, converts 5.6 to
                       // complex(5.6,0)
                       // and assigns to z
```

explicit

- However, implicit conversions may cause unexpected effects:

```
Vector(int); // defined constructor with int parameter
Vector v = {2, 5, 8};
v = 10;      // converts 10 to Vector(10) and assigns to v
void do_something(vector v);
do_something(7); // call with a vector of 7 elements
```

- A constructor defined **explicit** provides only the usual construction semantics and **not the implicit conversions**

```
class Vector {
  explicit Vector(int);
Vector v(10); // OK, explicit
v = 40; // error, no int-to-vector conversion
```

איך לאתחל וקטור ?

1. Initialize to default and then **assign**:

```
Vector v1(2); // error prone:
v1[0] = 1.2; v1[1] = 2.4; v1[2] = 7.8; //
```

2. Use **push_back**:

```
Vector v2;     // tedious
v2.push_back(1.2); v2.push_back(2.4); v2.push_back(7.8);
```

- push_back **is useful** for input:

```
read(istream& is, Vector& v) {
   for(double d; is >> d;) v.push_back(d)
}
```

3. Best use **{ } delimited** list of elements:

```
Vector v3 = {1.2, 7.89, 12.34}; // C++11
```

בנאי לאתחול מרשימה

- A **{ } delimited** list of elements of type T is presented to the program as an object of type **initializer_list<T>**

```
class Vector {
     int sz;           // the size
     double* elem; // a pointer to the elements
public:
     Vector(initializer_list<double> lst) // constructor
          :sz{lst.size()}, elem{new double[sz]}
          { copy( lst.begin(),lst.end(),elem); }
          // copy using standard library algorithm
};
Vector v1(3);     // three elements
vector v2{3};     // one element
vector v3 = {3}; // one element
```

default copy constructor (בנאי העתקה (ברירת מחדל

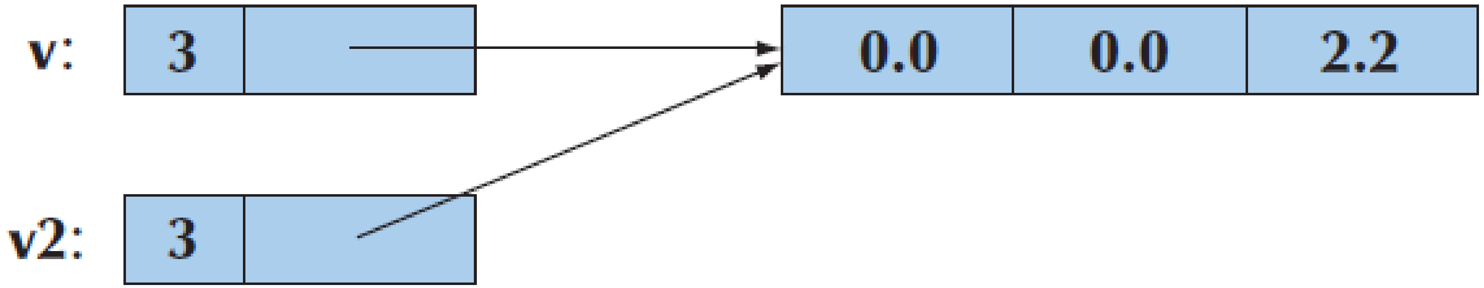
- The default meaning of copy is member-wise copy:

```
Vector v2(v); // use copy constructor
Vector v2 = v; // use copy constructor
```

- For the vector **pointer member** it means:

```
v2.elem == v.elem
```

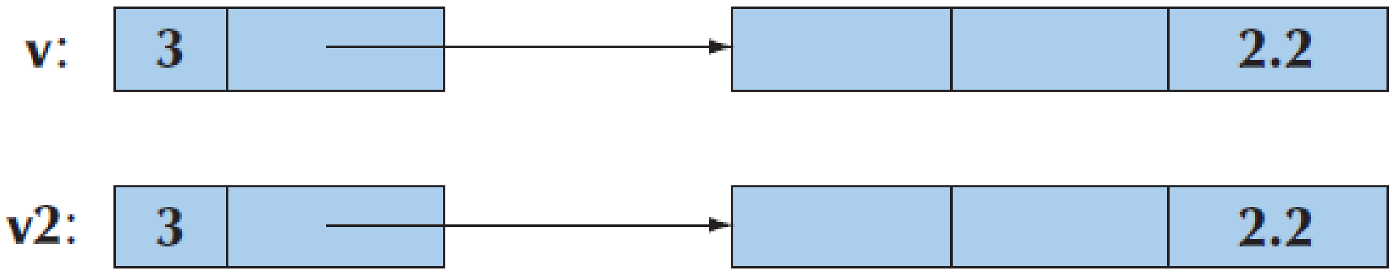
- **v2** doesn't have a **copy** of **v** elements as expected , but **shares** **v** elements
- When the **destructors** for **v** and **v2** are implicitly called, memory will be **freed twice**



בנאי העתקה שמעתיק כראוי copy constructor

- The constructor should **allocate** memory for the elements before copying:

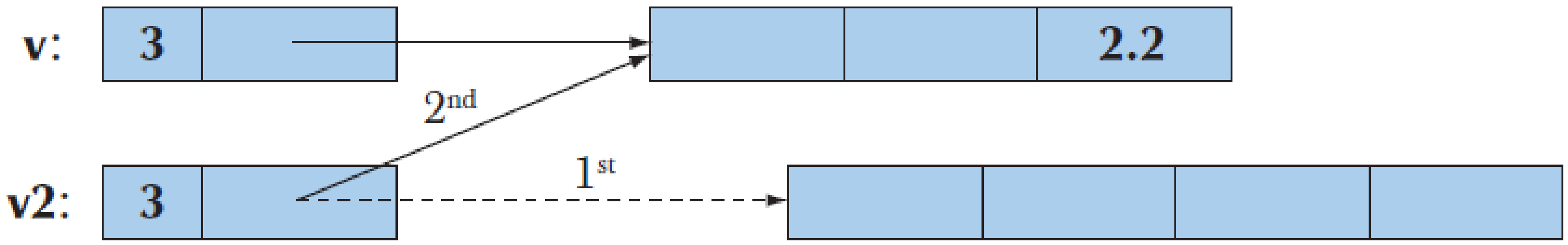
```
class Vector {
    int sz;
    double* elem;
public:
    Vector(const Vector& rhs) ; // define copy
constructor
        :sz{rhs.sz}, elem{new double[rhs.sz]};
        { copy(rhs.elem, rhs.elem+sz, elem); }
```



default copy assignment (השמת העתקה (ברירת מחדל

- As with copy initialization, the default meaning of **copy assignment** is member-wise copy
- Assignment will cause a **double deletion** and **memory leak**

```
Vector v(3);
v[2] = 2.2;
Vector v2(4);
v2 = v;
```

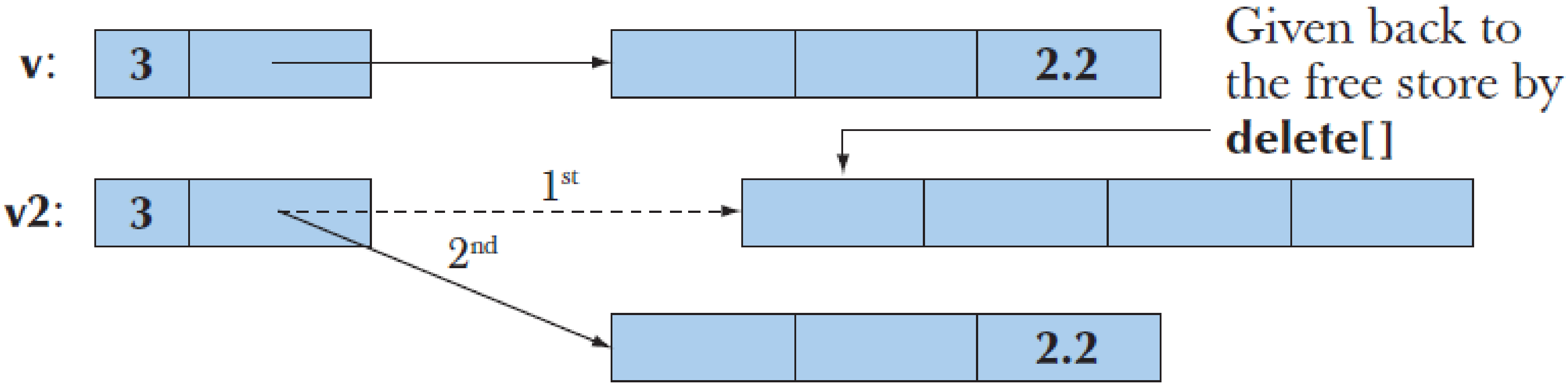


השמת העתקה שמעתיקה כראוי copy assignment

```
class Vector {
    Vector& operator=(const Vector&) ; // copy assignment
// . . .
Vector& Vector::operator=(const Vector& rhs)
{
    double* p = new double[rhs.sz];     // allocate space
    copy(rhs.elem, rhs.elem+rhs.sz, p); // copy elements
    delete[] elem; // deallocate old space
    elem = p;      // reset elem
    sz = rhs.sz;
    return *this;  // return a self-reference
}
```

העתקה כראוי

- We make a copy of the elements from the source vector
- **Then** we free the old elements from the target vector
- Finally, we let elem point to the new elements
- The case of **self assignment** (`v = v;`) is handled correctly



- **Shallow copy** copies only a pointer so that the two pointers now refer to the same object
- **Deep copy** copies what a pointer points to so that the two pointers now refer to distinct objects

מניעת העתקה (= delete)

- we can prevent copies by defining the copy constructor and copy assignment operator as **deleted** functions:

```
struct NoCopy {
NoCopy() = default;  // use the default constructor
NoCopy(const NoCopy&) = delete;               // no copy
NoCopy &operator=(const NoCopy&) = delete; // no assignment
~NoCopy() = default; // use the default destructor
// other members
};
```

lvalue and **rvalue**

- An **lvalue** can appear on the left side of an assignment operator
  - It is is an object that **can be modified**
- An **rvalue** appears on the right side of an assignment expression
  - It is an expression that identifies something **temporary** that **can not be modified**
- In the assignment statements:

```
y = x + 2; // y is an lvalue,  x + 2 is an rvalue
z = 7;     // z is an lvalue,  7 is an rvalue
s = f(x);  // f(x) is an rvalue
x + 2 = y; // Error
7 = z;     // Error
f(x) = s;  // Error
```

rvalue references

- It is illegal to assign a temporary rvalue to a reference variable:

```
int i = 42;
int& r = i;          // OK
int& r = x + 3;      // Error
```

- The following function call is illegal:

```
int f(int& n) { return 10 * n; }
x = f(x + 2);
```

- C++ **does** have an **rvalue reference**:

```
int&& r = x + 3; // OK: note the two ampersands
int&& rr = i;    // Error: cannot reference an lvalue
```

- The following function call is OK:

```
int g(int&& n) { return 10 * n; }
x = g(x + 2);
```

העמסת פונקציות עם & ו- &&

```
void ref(int& n) {
   cout << "reference: " << n << endl;
}
void ref(int&& n) {
   cout << "rvalue reference: " << n << endl;
}

int main() {
     int x = 10;
     ref(x);                       // lvalue
     ref(x + 10);                  // rvalue
     ref(30);                      // rvalue
     ref(std::move(x));            // lvalue cast to rvalue
}
```

rval.cpp

בנאי הזזה

```
Vector::Vector(Vector&& rhs)
    :sz{rhs.sz}, elem{rhs.elem} // move rhs.elem to elem
{
    rhs.sz = 0;                 // make rhs empty
    rhs.elem = nullptr;
}

vector fill(istream& is) {
    vector res;
    for (double x; is>>x; ) res.push_back(x);
    return res;
}
vector vec = fill(cin);
```

- Copying res out of fill() and into vec could be expensive, the **move constructor** is implicitly used to implement the return

השמת הזזה

```
Vector& Vector::operator=(Vector&& rhs)
{
    delete[] elem;          // deallocate old space
    elem = rhs.elem;        // move rhs.elem to elem
    sz = rhs.sz;
    rhs.elem = nullptr;     // make rhs the empty vector
    rhs.sz = 0;
    return *this;           // return a self-reference
}
```

- If the caller passes an **rvalue**, the compiler generates code that invokes the **move constructor** or **move assignment** operator
- We thus avoid making a copy of the temporary

פעולות נדרשות במחלקה שמשתמשת במשאבים

- A class needs a **destructor** if it **acquires resources**:
  - The obvious example is **memory** that you get from the free store (using **new**) and have to give back to the free store (using **delete** or **delete[]**)
  - Other resources are **files** (if you open one, you have to close it), **locks**, **thread handles**, and **sockets** (for communication)
- If a class has a **destructor**, it is likely to need all the following functions:

```
X();                          // default constructor
X(Sometype);                  // ordinary constructor
X(const X&);                  // copy constructor
X(X&&);                       // move constructor
X& operator=(const X&);       // copy assignment
X& operator=(X&&);            // move assignment
~X();                         // destructor
```

העמסת [ ]

```
double operator[] (int i) {
    return elem[i];
}
```

- However, letting the subscript operator **return a value** enables **reading** but not **writing** of elements:

```
Vector v(10);
double x = v[2]; // fine
v[3] = x;        // error, v[3] is not an lvalue
```

- We have to **return a reference** from the subscript operator:

```
double& operator[ ](int n)
{
    return elem[n];
}
```

העמסת [ ] לפי const

- The subscript operator defined so far has a problem, it cannot be invoked for a **const** vector.
- Only **const** member functions can be invoked for **const** objects:

```
void f(const vector& cv)
{
    double d = cv[1]; // Error, but should be fine
    cv[1] = 2.0;      // Error, as it should be
}
```

- The solution is to provide a version that is a **const** member function:

```
double& operator[] (int n); // for non-const
const double& operator[] (int n) const; // for const
```

כללי העמסת +

- we define the arithmetic and relational operators as **nonmember** functions
  - in order to allow **conversions** for either the left- or right-hand operand
- These operators need not change the state of either operand
  - so the parameters are ordinarily references to **const**
- Classes that define an arithmetic operator generally define the corresponding **compound assignment operator**
- It is usually more efficient to define the arithmetic operator **to use compound assignment**:

```
Sales_data
operator+(const Sales_data &lhs, const Sales_data &rhs)
{
	Sales_data sum = lhs; // copy from lhs into sum
	sum += rhs;           // add rhs into sum
	return sum;
}
```

העמסת + לוקטור

```
Vector operator+(const Vector& a, const Vector& b)
{
    if (a.size()!= b.size())
        throw Vector_size_mismatch{};
    Vector res(a.size());
    for (int i = 0 ; i != a.size() ; ++i)
        res[i] = a[i] + b[i];
    return res;
}

Vector r;
r = x + y;
```

העמסת אופרטור הפלט >> לוקטור

```
ostream& operator<<(ostream& os, const Vector& vec)
{
    os << '{';
    int n = vec.size();
    if (n > 0) {      // Is the vector non-empty?
        os << vec[0]; // Send first element
        for (int i = 1; i < n; i++)
            os << ',' << vec[i];
    }
    os << '}';
    return os;
}

cout << vec1 << endl;
```

איטרטורים

```
class Vector {
    int sz;         // size
    double* elem; // pointer to the elements
public:
    typedef double* iterator;
    typedef const double* const_iterator;

    iterator begin() { return elem; }
    const_iterator cbegin() const { return elem; }
    iterator end() { return elem+sz; }
    const_iterator cend() const { return elem + sz; }
// . . .
};
```

תבנית

- We don’t want just vectors of doubles, we want to specify the element type

```
template<typename T>
class Vector {
  T* elem; // elem points to an array of type T
  int sz;
public:
  explicit Vector(int s);
  T& operator[](int i);
  const T& operator[](int i) const;
};
template<typename T>
Vector<T>::Vector(int s) { . . . elem = new T[s]; . . .}
```

exceptions חריגות

- One effect of the modularity of a program, is that the point where a run-time error can be **detected** is separated from the point where it can be **handled**
- Consider a Vector, what ought to be done when we try to access an element that is **out of range** for the vector
  - The writer of Vector **doesn’t know** what the user would like to do in this case
  - The user of Vector **cannot** consistently detect the problem
- The solution is for the Vector implementer to detect the attempted out-of-range access and then **tell the user** about it

throw

- Vector::operator[ ] can detect an attempted out-of-range access and throw an out_of_range exception

```
double& Vector::operator[](int i)
{
    if (i < 0 || i >= size())
        throw out_of_range{"Vector::operator[]"};
    return elem[i];
}
```

- The throw transfers control to a handler for exceptions of type **out_of_range** in some function that called Vector::operator[ ]
- The out_of_range type is defined in the **standard library**

try and catch

- The implementation will unwind the function **call stack** as needed to get back to the context of the caller that has expressed interest in handling that kind of exception
- The standard library does not throw out_of_range for **subscript** operator, but throws for **at**()

```
try { // exceptions are handled below
   // v[v.size()] = 7; // returns an undefined value
   v.at(v.size) = 7     // reports a bad index
}
catch (out_of_range) { // oops: out_of_range error
   // ... handle range error ...
}
```

מימוש לא יעיל - push_back()

```
void Vector::push_back(const double& val)
{
        double* p = new double[sz+1];
        copy(elem, elem+sz, p);
        p[sz] = val;
        delete[] elem;
        elem = p;
        ++sz;
}
```

- Problem, for each push_back() we have to **copy** the whole vector

```
v.push_back(7); // need more space
v.push_back(8); // need more space
```

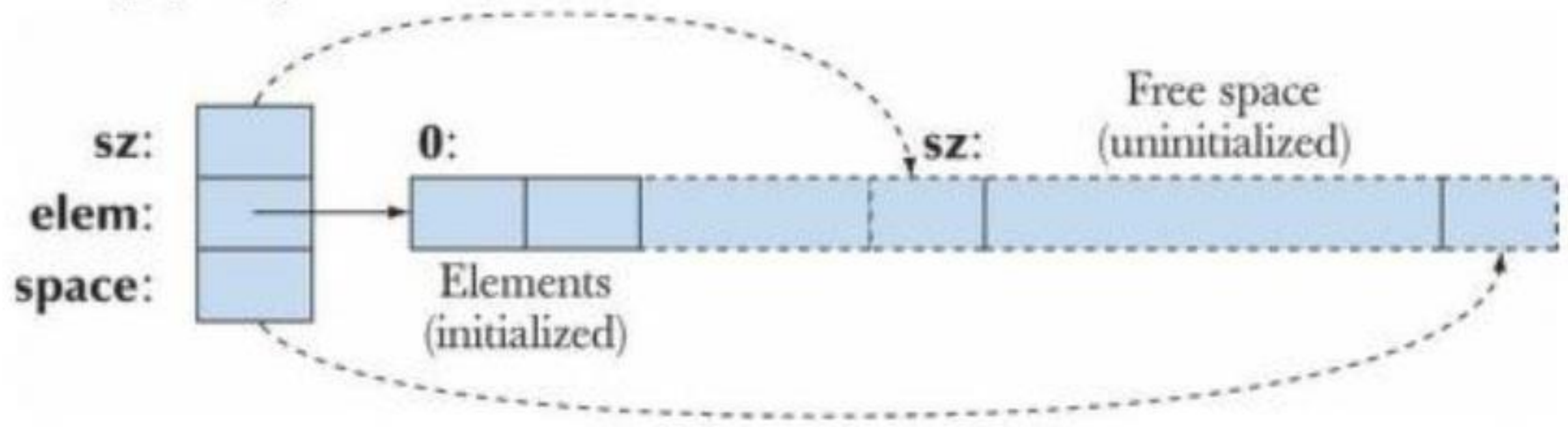
push_back()

- To avoid copying, we have to allocate extra space and keep track of both the **number of elements** and **amount of space** allocated

```
class Vector {
  int sz;       // size of vector
  int space;    // space allocated
  double* elem; // a pointer to the elements
```

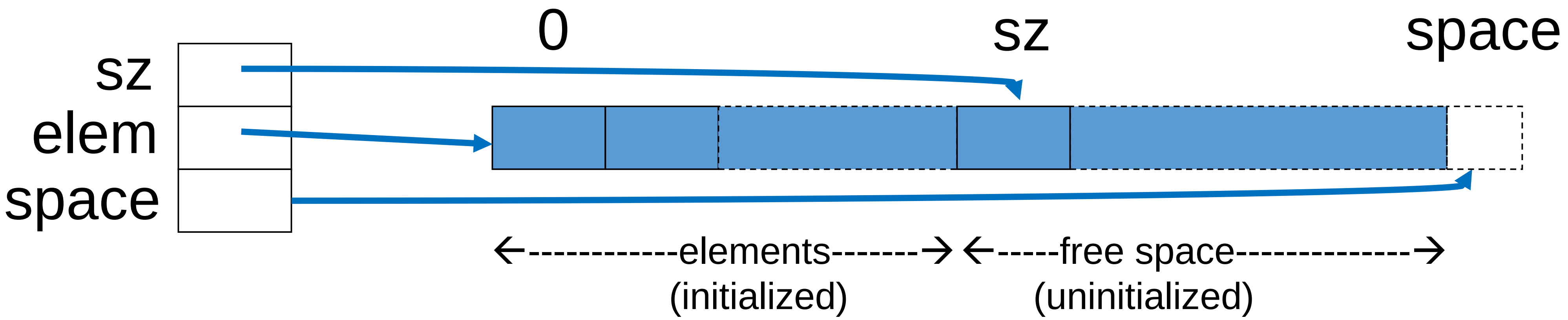
- The default constructor creates an empty vector:

```
Vector():sz{0}, space{0}, elem{nullptr} {}
```

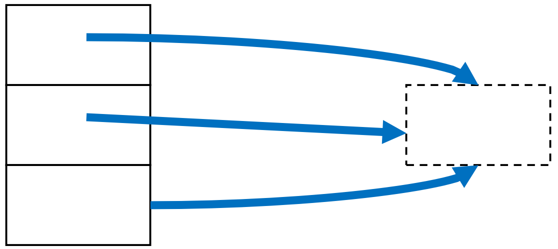


ייצוג וקטור

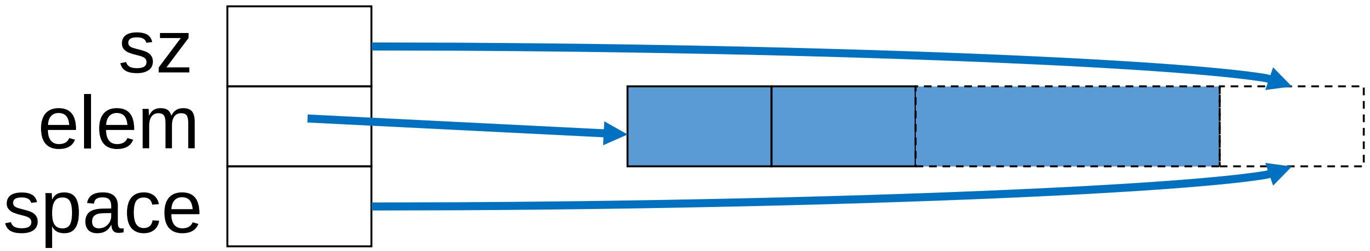
A vector(n) (free space)



An empty vector(no free store use)



A vector(n) (no free space)



מימוש יעיל - push_back()

```
void Vector::reserve(int newalloc) {
    double* p new double[newalloc];
    for (int i=0; i<sz; ++i) p[i] = elem[i];
    delete[] elem;
    elem = p;
    space = newalloc;
}
void Vector::push_back(double val) {
    if (space == 0) reserve(8);
    else if (sz == space) reserve(2*space);
    elem[sz] = val;
    ++sz;
}
```