Efficient Programming

- Designing and building efficient programs efficiently requires knowledge and practice
  - Hopefully the programming language helps, it’s not intended to get in the way
  - Object-oriented concepts, and more general programming concepts help in developing programs
  - Knowledge of data structures and algorithms helps

- Tools of the engineer/scientist programmer
  - A library or toolkit is essential, don’t reinvent the wheel
  - Someone must build the tools
  - Programming is not just art, not just science, not just engineering

See readwords.cpp

- This reads words, how can we count different/unique words?

  tvector<string> list;
  string filename, word;
  cin >> filename;
  ifstream input(filename.c_str());
  CTimer timer;
  timer.Start();
  while (input >> word) {
    list.push_back(word);
  }
  timer.Stop();
  cout << "read " << list.size() << " words in ";
  cout << timer.ElapsedTime() << " seconds" << endl;

Measuring performance of algorithms

- How fast is fast enough?

  bool search(const tvector<string> & a,  
               const string & key)  
    // pre:  a contains a.size() entries  
    // post: return true if and only if key found in a  
    int k; int len = a.size();
    for(k=0; k < len; k++)
      if (a[k] == key) return true;
    return false;

- In “early years”, time this function on vectors of different sizes, compute a measure for a specific machine/architecture
- In current times: how fast on P300, P500, G4, ultraspark?
  - Does compiler make a difference? Other factors?

Review/Preview: Anagrams/Jumbles

- Brute-force approach to finding anagrams/solving jumbles
  - Brute-force often thought of as "lack of thought"
  - What if the better way requires too much thought?
  - What if there’s nothing better?
  - nelir,nerli, neir, neirl, neril, nier, nleri, nirei, nri, nir, nirle, nirler, nirile,
    nileir, niler, nri, nirle, ri, nelir, ler, lenr, lerin, lerni, lneri
  - What’s the problem here?
  - Is there a better method?
Brute force?  **permana.cpp**

```cpp
// find anagram of word in wordSource
// list is a vector [0, 1, 2, .., n]
Permuter p(list);
int count = 0;
string copy(word); // makes copy the right length
for(p.Init(); p.HasMore(); p.Next()){
    p.Current(list);
    for(k=0; k < list.size(); k++)
        copy[k] = word[list[k]];
    if (wordSource.contains(copy))
        cout << "anagram of " << copy << endl;
        break; // find first anagram only
}
```

---

**Quantifying brute force for anagrams**

- On one machine make/test a word takes $10^{-5}$ seconds/word
  - $9!$ is 362,880, how long does this take?
  - What about a ten-letter word?

- We’re willing to do some pre-processing to make the time to find anagrams quicker
  - Often find that some initialization/up-front time or cost saves in the long run
  - We need a better method than trying all possible permutations
  - What properties do words share that are anagrams?

---

**Preliminaries: C++ in permana.cpp**

- What is a dictionary?
  - What is a class, what are the methods, why use it?
  - What properties of the class do methods depend on, class invariants?

- What is a tvector and why is it used instead of an array?
  - How are elements added to the vector?
  - Differences between tvector and vector (STL class)?

- What is a Permuter and how does it work?
  - Where is information about this class found?
  - What patterns of use does a permuter exhibit?

---

**Toward a faster anagram finder**

- Words that are anagrams have the same letters; use a letter fingerprint or signature to help find anagrams
  - Count how many times each letter occurs:
    - “teacher” 1 0 1 0 2 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0
    - “cheater” 1 0 1 0 2 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0

- Store words, but use fingerprint for comparison when searching for an anagram
  - How to compare fingerprints using `operator ==`
  - How to compare fingerprints using `operator <`

- How do we make client programmers unaware of fingerprints? Should we do this?
OO and C++ features we’ll use

- We’ll use an adapter or wrapper class called Anaword instead of a string
  - Clients can treat Anaword objects like strings, but the objects are better suited for finding anagrams than strings
  - The Anaword for “bear” prints as “bear” but compares to other Anaword objects as $11001000000000000100000000$

- C++ allows us to overload operators to help, not necessary but good cosmetically
  - Relational operators == and <
    - What about other operators: >, <=, >=, and !=
  - Stream operator <<

- How should we implement overloaded operators?

Overloaded operators

- Typically operators need access to internal state of an object
  - Relational operators for Date, string, BigInt?
  - Where is “internal state”?

- For technical reasons sometimes operators should not be member functions:
  - BigInt $b = \text{enterBigValue}();$
    - if ($b < 2$) ...
    - if ($2 > b$) ...
  - We’d like to use both if statements, only the first can be implemented using $\text{BigInt::operator <}$ (why?)

- Use helper member functions: equals, less, toString
  - Implement overloaded operators using helpers

From operators to templates

- What kind of object can we put in a vector?
  - What kind of object can we sort?
  - What kind of object can we print: `cout << t << endl;`

- What is a vector? How is it different from the class Date?
  - Container class, what does it contain? Why use it?

- Genericity is a good thing, program to a more abstract idea rather than something more concrete
  - Sorting function for sorting int, string, double, ...
  - In C++ genericity done with templates and sometimes with inheritance; useful in different situations

Selection Sort: The Code (`selectsort2.cpp`)

```cpp
void SelectSort(vector<int> & a)
// pre: a contains a.size() elements
// post: elements of a are sorted in non-decreasing order
{
    int j, k, temp, minIndex, numElts = a.size();
    // invariant: a[0],...a[k-1] in final position
    for (k = 0; k < numElts - 1; k++)
        { // minimal element index
            minIndex = k;
            for (j = k + 1; j < numElts; j++)
                { if (a[j] < a[minIndex])
                    { minIndex = j; // new min, store index
                        }
                    }
            temp = a[k]; // swap min and k-th elements
            a[k] = a[minIndex];
            a[minIndex] = temp;
        }
```
What changes if we sort strings?

- The parameter changes, the definition of temp changes
  - Nothing else changes, code independent of type
  - We can use features of language to capture independence

- We can have different versions of function for different array types, with same name but different parameter lists
  - Overloaded function: parameters different so compiler can determine which function to call
  - Still problems, duplicated code, new algorithm means ...

- With function templates we replace duplicated code maintained by programmer with compiler generated code

Creating a function template

```cpp
template <class Type>
void SelectSort(vector<Type> & a) // pre: a contains a.size() elements
    // post: elements of a are sorted in non-decreasing order
    {
        int j,k,minIndex,numElts = a.size();Type temp;
        // invariant: a[0]..a[k-1] in final position
        for(k=0; k < numElts - 1; k++) // minimal element index
            for(j=k+1; j < numElts; j++)    // minimal element index
                if (a[j] < a[minIndex])
                    { minIndex = j; // new min, store index }
        temp = a[k]; // swap min and k-th elements
        a[k] = a[minIndex];
        a[minIndex] = temp;
    }
```

- When the user calls this code, different versions are compiled

Some template details

- Function templates permit us to write once, use several times for several different types of vector
  - Template function “stamps out” real function
  - Maintenance is saved, code still large (why?)

- What properties must hold for vector elements?
  - Comparable using < operator
  - Elements can be assigned to each other

- Template functions capture property requirements in code
  - Part of generic programming
  - Some languages support this better than others

Templates and function objects

- In a templated sort function vector elements must have certain properties (as noted previously)
  - Comparable using operator <
  - Assignable using operator =
  - Ok for int, string, what about Date? ClockTime?

- What if we want to sort by a different criteria
  - Sort strings by length instead of lexicographically
  - Sort students by age, grade, name, ...
  - Sort stocks by price, shares traded, profit, ...

- We can’t change how operator < works
  - Alternative: write sort function that does NOT use <
  - Alternative: encapsulate comparison in parameter, pass it
Function object concept

- To encapsulate comparison (like operator <) in a parameter
  - Need convention for parameter: name and behavior
  - Other issues needed in the sort function, concentrate on being clients of the sort function rather than implementors
- Name convention: class/object has a method named compare
  - Two parameters, the vector elements being compared (might not be just vector elements, any two parameters)
- Behavior convention: compare returns an int
  - zero if elements equal
  - +1 (positive) if first > second
  - -1 (negative) if first < second

Function object example

class StrLenComp
{
public:
  int compare(const string& a, const string& b) const // post: return -1/0/1 as a.length() < b.length()
  {
    if (a.length() < b.length()) return -1;
    if (a.length() > b.length()) return 1;
    return 0;
  }
};
// to use this:
StrLenComp scomp;
if (scomp.compare("hello", "goodbye") < 0) …

Another function object example

- Consider “directory.h” and the class DirEntry
  - DirEntry encapsulates file/directory
  - Methods: Name(), Size(), Path(), GetTime(), …
- To sort using Name() use class below, what about Size() ?

class DirNameComp
{
public:
  int compare(const DirEntry& a, const DirEntry& b) const // post: return -1/0/1 as a.Name() < b.Name()
  {
    if (a.Name() < b.Name()) return -1;
    if (a.Name() > b.Name()) return 1;
    return 0;
  }
};

Pointers

- Pointers are essential in many programming applications
  - Indirect references are often useful
    - Publish your email as foo@hotmail.com, but forward it to wherever you “really” are as you change jobs, for example
  - Allow data to be shared rather than duplicated
    - Sort a list of people/grades by name and by grade, we can maintain one list of people, and two lists of indexes, one sorted by name, one sorted by grade
  - Facilitate inheritance
    - Essential for OO
  - Implement data structures
    - Lists, trees, …
Syntax and semantics of pointers

```cpp
void foo()
{
    string s("hello");
    string * sp = new string("world");
    string * sp2;
    int slen = s.length();
    int splen = sp->length();
    // splen = (*sp).length();
    int splen2 = sp2->length();
}
```

- Memory allocated dynamically using `new`
- What happens to `s` when `foo` terminates?
- Dereference a pointer using `*`, get at the object pointed to
- `a->` is shorthand for `(*a)`
- Pointers that don’t point at something are BIG TROUBLE

Vectors of pointers

```cpp
void readWords(istream& input, tvector<string>& list)
// post: all words in input stored in list
{
    string word;
    while (input >> word)
    {
        list.push_back(word);
    }
    cout << "read " << list.size() << " words" << endl;
}
```

- What changes if we use `tvector<string *>` instead?
- What happens if we use code below which uses the address-of operator for vector of pointers (don’t do this at home)

```cpp
list.push_back(&word);
```

Sidebar: implementing swap in C

- Unlike C++, there are no reference parameters in C
- Simulate pass-by-reference using pointers, what happens to actual parameters `x` and `y` in code below?

```c
void swap(string& a, string& b)
{
    string temp = a;
    a = b;
    b = temp;
}
```

```c
int main()
{
    string x("first"), y("second");
    swap(x, y);
}
```

Implementing swap in C

- In C we must pass pointers, and use address-of operator to simulate reference parameters, is the picture different?
- In C++ the pointers are hidden, harder to make mistakes?

```c
void swap(string * a, string * b)
{
    string temp = *a;
    *a = *b;
    *b = temp;
}
```

```c
int main()
{
    string x("first"), y("second");
    swap(&x, &y);
}
```