Implementation Techniques
and other stuff for practical contests

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Talk overview

A collection of tips and tricks:

- editing
- compiling
- testing
- debugging
- implementation
- ... and more
Choose your tools

Programming contests are not only about solving problems.

Hardest part: statement $\rightarrow$ solution idea.

Your goal: spend as much time as possible on the hardest part
In other words: spend as little time as possible on everything else.

What helps: good tools, a good strategy, lots of practice

Language choice for contests: C++ is the winner
Editor

Does the editor matter?

All editors are more or less the same when you write code. The difference appears once you need to edit it.

Essentials

- syntax highlighting
- automatic indentation

Bonuses

- quick and simple searching, replacing, indentation, etc.
- interaction with the compiler
- **vim** does all of this and more – run **vimtutor** to get a taste
Compiler: Use warnings!

```cpp
warnings.cc

#include <iostream>
using namespace std;

int compute() {
    int a, b;
    cin >> a;
    if (a==0) {
        cout << "zero" << endl;
        return b;
    } else {
        cout << "non-zero" << endl;
    }
}

int main() {
    if (compute()) cout << "success" << endl;
}
```

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Compiler: Use warnings!

Compiler output without warnings

(That is, absolutely none!)

Compiler output with g++ -W -Wall warnings.cc

warnings.cc:7: warning: suggest parentheses around assignment used as truth value
warnings.cc:13: warning: control reaches end of non-void function
warnings.cc:9: warning: ‘b’ may be used uninitialized in this function
Compiler: Use warnings!

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Compiler output with `g++ -W -Wall warnings.cc`

```
warnings.cc:7: warning: suggest parentheses around assignment used as truth value
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warnings.cc:9: warning: ‘b’ may be used uninitialized in this function
```
The bash shell is your friend

Input/output redirection

```
./my_program < task.in > task.my_out
```

Input straight from the command line

```
./my_program <<< "5 1 2 3 4 5"
```

Very useful e.g. when writing generators

Check whether your output is correct

```
diff task.my_out task.correct
```

(Learn to read diff’s output
or use “diff -y” to see both files side by side.)
The bash shell is your friend

**For-cycles, variables, wildcards**

```sh
for i in a b c ; do echo $i ; done
for i in *.in ; do echo $i ; done
for i in *.in ; do ./my_program < $i ; done
```

**Sequences**

```sh
seq $start [$end [$step]]
```

For example:

```sh
seq 47
```

prints 1 to 47

```sh
seq 1 12 3
```

prints 1 4 7 10

**Expressions**

```sh
echo $(( 4 + ( 7 * 1 ) ))
```
The bash shell is your friend

A complete script testall.sh

```bash
#!/bin/bash
for infile in *.in ; do
    echo $infile
    name=`basename $infile .in`
    outfile=$name.out
    myfile=$name.my

    time ./my_program < $infile > $myfile
diff -q $myfile $outfile
done
```

Make it executable

```bash
chmod a+x testall.sh
```
Debugging 1: the real deal

Knowing `gdb` or a frontent (such as `ddd`) may be an advantage.

**Very simple usage**

```
$ g++ error.cc -g -o error
$ ./error
Floating point exception
$ gdb ./error
(gdb) run
Starting program: /home/misof/SANDBOX/error
Program received signal SIGFPE, Arithmetic exception.
0x00000000000400946 in main () at error.cc:10
10  s += 100 / A[10];
(gdb) print A[10]
$1 = 0
```
assertions = checks that the data is still sane

Assertions in C++

```cpp
#include <cassert>
...
int x = foo();
assert( (x>=0) && (x<N) );
```

... and the code is executed

```cpp
assert: assert.cc:8: int main():
Assertion ‘(x>=0) && (x<N)’ failed.
```

asserts cost you nothing:
just add “#define NDEBUG” before “#include”’s to disable them.
Debugging 2: asserts

Assertions in FreePascal

```pascal
{$C+}
var x : longint;
...
x := foo();
assert( (x>=0) and (x<N) );
```
Never delete debug outputs – just make them inactive!

Debug outputs using the preprocessor

```c
x := foo();
#ifndef NDEBUG
    cerr << "x: " << x << endl;
#endif
```

A handy macro

```c
#ifdef NDEBUG
#define DEBUG(x)
#else
#define DEBUG(x) cerr << #x << ": " << (x) << endl;
#endif
```
Avoid Copy&Paste like the Plague

Copy and Paste

- one of the most frequent bug sources
- produces long code: hard to read, hard to modify
- if you introduce a bug, it’s impossible to find
- almost never necessary!

How to avoid it?

- implement each functionality once, and once only
- one option: wrap it in a function
- another option: replace it with a loop
Copy&Paste case study: Maze exploration

navigating a 4-connected maze

```c
int dr[] = {-1, 0, 1, 0};
int dc[] = {0, 1, 0, -1};
// generate all 4 cells reachable from (r,c):
for (int dir=0; dir<4; ++dir) {
    int nr = r + dr[dir];
    int nc = c + dc[dir];
    ...
}
// Note: (dir+1) % 4 is the next direction clockwise
```

knight moves?

```c
int dr[] = {-2, -2, -1, -1, 1, 1, 2, 2};
int dc[] = {-1, 1, -2, 2, -2, 2, -1, 1};
for (int dir=0; dir<8; ++dir) ...
```
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knight moves?

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int dr[] = {-2, -2, -1, -1, 1, 1, 2, 2};
int dc[] = {-1, 1, -2, 2, -2, 2, -1, 1};
for (int dir=0; dir<8; ++dir) ...
```
Sentinels

Special cases are bad:
– you are forced to write more code
– you may make more bugs

An useful technique: sentinels

idea: add new data with extremal values
result: each original item is processed in the same way

Example #1

- data: a sorted array
- goal: find the number of unique elements
- sentinels: add “∞” at the end
- gain: one for-cycle with no special cases
Sentinels

Example #2
- data: a sorted array
- goal: binary searching for many $x$s
- sentinels:
  - add a $-\infty$ value at the beginning,
  - add a $\infty$ at the end
- gain: easier binary search: $x$ is always inside

Example #3
- data: halfplanes
- goal: compute their intersection
- sentinels: start with a huge bounding box
- gain: no infinity as a special case
Overview
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Sentinels

Example #4

- data: a bitmap of a maze
- goal: exploration
- sentinels: add a row/column of walls at each side
- gain: no need for checks like
  \[
  \text{if} \ ( (r \geq 0) \ \&\& \ (r < R) \ \&\& \ (c \geq 0) \ \&\& \ (c < C)) \ldots
  \]

```

########
..##...#.
##...##...#
..##...##...#
.##...##...##
..##...##...##
.##...##...##

########
```

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Implementation Techniques
Binary search

Binary search is easy:

```cpp
int binary_search(const vector<int> &array, int value) {
    // initialize pointers to the first and last element
    int start = 0, end = array.size()-1;
    // check whether value falls outside of the array
    if (value < array[start]) return -1;
    if (value > array[end]) return -1;
    // while we have multiple choices, halve the interval
    while (start != end) {
        int middle = (start+end)/2;
        if (array[middle] < value) start = middle; else end = middle;
    }
    if (array[start] == value) return start; else return -1;
}
```
int binary_search(const vector<int> &array, int value) {
    int start = 0, end = array.size()-1;
    if (value < array[start]) return -1;
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    while (start != end) {
        int middle = (start+end)/2;
        if (array[middle] < value) start = middle; else end = middle;
    }
    if (array[start] == value) return start; else return -1;
}

Does not even work for values actually present!
Example: array[]={0,10,20,30,40}, value=30
(start, end): (0, 4) → (2, 4) → (2, 3) → (2, 3) → ···
Half-open intervals

The previous example
bug type: ±1 errors
how to avoid: always see a clear invariant
one helpful technique: half-open intervals

What’s a half-open interval?

\([a, b) = \{x \mid a \leq x < b\}\)
Read: \(a\) is the first number inside, \(b\) the first one outside

Useful to learn: used e.g. in STL, in Python
in general, they lead to code with few ±1s
Half-open intervals

**Basic properties**

**Length**: $b - a$ (also the number of integers in range)

Natural representation of an empty range: $[a, a)$.

For any $c$ such that $a < c < b$ we can split interval $[a, b)$ into $[a, c)$ and $[c, b)$.

**Example: binary search**

- In the beginning:
  
  make sure that $array[a] \leq value < array[b]$.

- When to terminate:
  
  as soon as $b - a = 1$: now $a$ is the only candidate left

- How to proceed if $b - a > 1$:
  
  split $[a, b)$ into $[a, c)$ and $[c, b)$ for $c = (a + b) \div 2$
Half-open intervals

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Example: binary search

- In the beginning:
  make sure that $array[a] \leq value < array[b]$.
- When to terminate:
  as soon as $b - a = 1$: now $a$ is the only candidate left
- How to proceed if $b - a > 1$:
  split $[a, b)$ into $[a, c)$ and $[c, b)$ for $c = (a + b) \div 2$
Half-open intervals

Fixed binary search

```cpp
int binary_search(const vector<int> &array, int value) {
    // ensure the precondition
    if (value < array[0]) return -1;

    // set the bounds
    int a = 0, b = array.size();

    // do the search
    while (b-a > 1) {
        int c = (a+b)/2;
        if (array[c] <= value) a=c; else b=c;
    }
    if (array[a] == value) return a; else return -1;
}
```

Note: we divided the array into a “good” and a “bad” part.
Half-open intervals

Prefix sums: the problem
You have: an unsorted array $A[0..N-1]$ of numbers
You want: quickly determine sum of any segment

Prefix sums: idea of the solution

Prefix sums: the solution
Note: $S[i]$ is the sum of elements of $A$ with indices in $[0, i)$.
Sum of segment with indices in $[a, b)$: simply $S[b] - S[a]$.
Half-open intervals

Prefix sums: the problem
You have: an unsorted array $A[0..N−1]$ of numbers
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Prefix sums: idea of the solution

$$(A[i] + \cdots + A[j]) = (A[0] + \cdots + A[j]) - (A[0] + \cdots + A[i−1])$$

Prefix sums: the solution


Note: $S[i]$ is the sum of elements of $A$ with indices in $[0, i)$.


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Half-open intervals

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Prefix sums: idea of the solution
$\left( A[i] + \cdots + A[j] \right) = \left( A[0] + \cdots + A[j] \right) - \left( A[0] + \cdots + A[i-1] \right)$

Prefix sums: the solution
Note: $S[i]$ is the sum of elements of $A$ with indices in $[0, i)$.
Sum of segment with indices in $[a, b)$: simply $S[b] - S[a]$. 
STL: Intro

STL: the Swiss Army Knife for programming contests.
(Some weird things like those little scissors, but several very useful tools.)

Template: code with a variable instead of a type.

Example code template

```cpp
template<class T> T sumSquares(T a, T b) { return a*a + b*b; }
```

Three basic parts of STL
- containers
- algorithms
- iterators
STL: Containers

A bunch of data structures for free

- **vector**: a scalable array
- **set**: a balanced binary tree
- **map**: a sorted associative array
- **priority_queue**: a heap
- **list**: a linked list
- **deque**: a double-ended queue (very convenient!)
- **pair**: an arbitrary ordered pair
- **string**: a convenient class for strings
Overview
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STL: Containers

Advantages of using STL containers

- As efficient as possible – if you use the right one!
- You do not reinvent the wheel
- Less bugs
- Shorter, more readable code
- Less time spent on the implementation
- BUT: you still have to understand what’s going on

Example: using a set

```cpp
set<int> S;
for (int i=0; i<1234567; ++i) S.insert(i);
S.erase(7);
cout << S.count(47) << " " << S.size() << endl;
```
STL: Iterators

What’s an iterator?

An iterator is a “smart” pointer.
The iterator “knows” what it points to.
- increased pointer: the next memory location
- increased iterator: the next element in the container!

All STL containers are the same

Each container has methods `begin()`, `end()`.
These return two iterators that determine a **half-open** range.
Three equal expressions: `empty()` ; `size()==0` ; `begin()==end()`

Iterating over all elements of a container:
`for (it = cont.begin(); it != cont.end(); ++it) process(*it);`
STL: Algorithms

And a bunch of algorithms for free

- **min, max**: comparison
- **min_element, max_element**: convenient linear search
- **swap**: exchange two elements
- **unique, reverse, rotate, random_shuffle**: array manipulation
- **sort, stable_sort, nth_element**: sorting and searching
- **lower_bound, upper_bound**: generalized bsearch
  (also set/map methods!)
- **next_permutation**: quickly try all possibilities
  (also works with equal elements!)
- **__gcd**: greatest common divisor (undocumented!)
next_permutation example

```cpp
// generate all numbers with digits 1,1,3,4,7 in sorted order
#include <algorithm>
#include <iostream>
using namespace std;
int A[] = {1,1,3,4,7};
int main() {
    do {
        for (int i=0; i<5; ++i) cout << A[i];
        cout << endl;
    } while (next_permutation(A,A+5));
}
```

Tip: iterate over all $K$-element subsets by filling $A$ with $N - K$ zeroes and $K$ ones (in this order!)
Bitsets

Subsets of 0, ..., N – 1

<table>
<thead>
<tr>
<th>a subset</th>
<th>0, 3, 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>good/bad numbers</td>
<td>0, 1, 2, 3, 4, 5</td>
</tr>
<tr>
<td>yes/no bits</td>
<td>1 0 0 1 0 1</td>
</tr>
<tr>
<td>the number</td>
<td>$2^0 + 2^3 + 2^5 = 41$</td>
</tr>
</tbody>
</table>

Bitwise operations

- **union**: bitwise or
- **intersection**: bitwise and
- **invert mask**: bitwise xor
- **set** $\{i\}$: bitwise shifts: $1 << i$
Bitsets

**Tricks to compute size**

```
int size=0, tmp=subset; while (tmp) ++size, tmp=tmp-1;
builtin_popcount(subset);
```

**Iterate over all subsets**

```
for (int subset=0; subset < (1<<N); ++subset) {
    for (int member=0; member<N; ++member) {
        if (subset & 1<<member) ...
    }
}
```

Important property: ∀A: all subsets of A are processed before A

Alternative for larger sets: `bitset<N>` in STL.
Contest strategy

Write a bruteforce solution!
- scores points!
- usually easy to implement (bitsets, next_perm)
- use it to test your faster solution (if any)
- combine both to be sure
- if enough time, write a generator as well

Optimizations?
- never prematurely!
- **never** overwrite, always back up a working version
- always compare both versions
Conclusions

- Correlation:
  - working, reliable code
  - short code
  - beautiful code

- Never reinvent the wheel.

- Programming is art, like poetry!

- Extend your “vocabulary”.

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