ustring

A Modern Alternative to std::string

Alan Talbot

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The Program

- Lecture
  - The Problem
  - The Solution
  - The Objections
  - The Proposal
- Feedback
  - Wherein everyone gets to offer suggestions, ideas, theories, criticisms, and ridicule

The Problem

- Strings
  - Almost every program deals with strings, and a large and important class of programs require very efficient string processing
  - Some programs have special string handling requirements
  - In our polyglot global world, string handling has become all the more challenging
- The venerable std::string
  - Has served us well for many years
  - Has some significant fundamental limitations
  - Has some rather annoying quirks
  - Lacks features that are common in other libraries and languages
  - Is not sufficiently global
  - Does not take advantage of modern C++ design (especially C++11)
- Therefore
  - Most significant programs need more than one string type
  - I typically use three in Windows programs: char arrays and pointers, std::string, and CString
  - This leads to kind of a mess

Inflexible Memory Model

- Local memory usage is implementation defined
  - Small string optimization is typically present
  - No size vs. speed control
  - Inefficient for small strings where memory is tight
- Growth behavior is implementation defined
  - Typical growth is exponential
  - Inefficient for small strings where memory is tight because of air
  - Inefficient or even impossible for strings that are large in relation to addressable memory size
- Not byte compatible with C-style char arrays
  - C-style arrays are sometimes what you have, but then copies are required
  - C-style arrays have advantages in some situations
- Cannot be used if a local-only (no heap) allocation is required
  - Cannot be efficiently embedded in composite structures where size optimization is desired

Interaction With C Strings

- Interaction with char arrays
  - To construct a std::string from a char array requires a copy
  - To get a char array back out of a std::string requires a copy
- Interaction with char*s
  - If you want to support both native strings and std::strings, you need (at least) two overloads:
    - void foo(const char* str);
    - void foo(const string& str);
  - If you have only the first, you can't use natural syntax—you have to use std::string::c_str(), and hope that it's free
  - If you have only the second, you'll get an extra construction, copy and destruction
  - Oh, by the way, all the Standard Library string manipulation routines are in C, so they take char* only

Functionality Limitations

- Many common operations are not directly supported
  - Trim
  - Make upper/lower
  - Case-insensitive compare
  - Token extraction
  - Format (a la printf)
- Most string manipulations are handled by the CRT
  - But the CRT is not well supported
  - Functions are not composable, and they use conflicting metaphors
- Unicode
  - std::string does not support Unicode
  - std:: wstring does not really support Unicode
  - No interoperability between these variants

Functionality Limitations

- Building strings
  - Building strings from other types (numbers, etc.) is not supported directly
  - Using std::stringstream is extra code and often inefficient
  - Using to_string is inefficient and inflexible
  - Using sprintf is downright ugly (and inefficient and unsafe)
  - Using non-portable OS code can be especially fun:

```
string s("X = ");
int dec;
int sign;
char* res = _fcvt(x, 3, &dec, &sign);
if (sign) s += '-';
s.append(res, dec);
s += '.';
s += res + dec;
```

Options

- Change std::string
  - This would necessarily mean backward compatibility
  - Which would involve compromises in design and functionality
  - There is strong resistance in the C++ Committee to changing std::string
- Add a layer on top of std::string
  - For example: string_ref
  - This would help a lot in some situations
  - But it would not solve the memory problems
- Write a new string library from scratch
  - This means a fresh start with no compromises due to backward compatibility
  - C++11 should be widely available by the time the library is ready to use
  - I believe the time is right for this to happen

The Solution

- Efficient
  - As with std::string, speed is a key consideration
  - Unlike std::string, efficiency of memory is also a key consideration
- Powerful
  - Programming should be intuitive and easy
  - Support all common operations in convenient, modern ways
  - Be very flexible without trying to do everything
- Compatible
  - Strings in a program should work together with each other and with other kinds of strings and existing functions
  - Be as similar as possible to std::string without introducing compromises
  - Have strong support for Unicode
- Useful
  - Offer an alternative to string, wstring, and CRT string handling
  - For most programs, all strings should be covered
  - For almost all programs, most strings should be covered

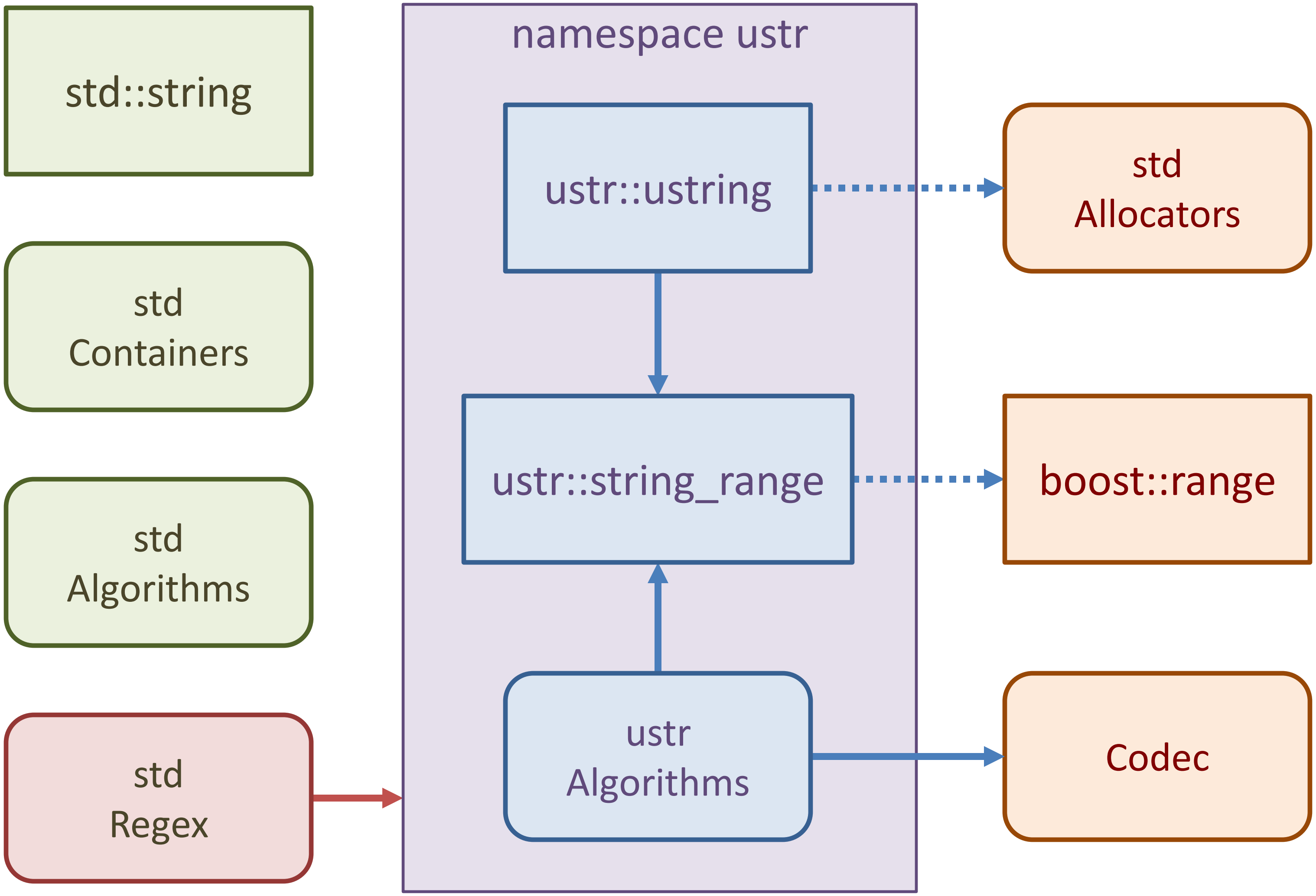
The Solution is Not

- A container—not quite
  - Most container properties are supported
  - It does not quite fully match an STL container concept due to some small differences
- A drop-in replacement for std::string
  - Full support of std::string functionality would mean supporting more than one metaphor
- A general purpose tool
  - The element type is not a parameter, it is an implementation-defined character type specific to the encoding
  - The size is limited (sort of) by the use of signed int size and position types
- Trying to be all things to all people
  - The goal is to solve a large class of very common string problems
  - Not trying to solve all text-related problems
  - Not a superset of all other string classes; for instance, it is not a rope
  - If you want a repository for your text editor, use a rope
  - If you want to a general container, use std::string or some other container

The Objections

- We don’t need more stinkin’ strings
  - I agree: we need fewer strings
  - To get there we need one that handles more situations more elegantly
- We have SGI Rope
  - Ropes optimize modification of very large strings
  - My concern is memory and speed efficiency for small strings or large, rarely modified strings
- We’ve been doing OK with std::string
  - std::string will probably never go away, but I believe std::string is no longer sufficient
  - My goal is to make std::string obsolescent (new code would be better served by the new string)
- But what about string_ref?
  - The ideas behind string_ref are incorporated into the string_range class
  - string_ref is not needed for this new string
  - Would be very nice for maintaining std::string code
- Anyway, strings should be immutable
  - Immutability has performance costs and is not compatible with embeddability
- So where’s the library?
  - Did you see the first slide?

The Ustring Library



What's in a name?

- **Unicode string**
  - Too limiting
- **Unified String**
  - Too unlimited
- **Ultimate string**
  - Too pretentious
- **Überstring**
  - Too cute
  - Unless you speak German, in which case too pretentious
- **Universal String**
  - Maybe
- **Useful String**
  - That's the idea
- Got a better name?
  - Doesn't have to start with U
  - Let me know (but not now)

The ustring Class Template

- Use a ustring wherever ownership of text is required
- One class template with several parameters
  - You will typically typedef several different variants for your application
- Template Arguments
  - Specify internal representation and encoding
  - Dictate the memory management strategy: local vs. heap (nothing to do with allocators)
  - Allocators may need to be added for Standard compliance to handle heap allocation
- Members
  - All length-modifying operations (e.g. Trim)
  - Some others are included for convenience (e.g. To Upper for simple encodings)

The ustring Class Template

- Internal representation
  - Character type
    - Specified by the Encoding parameter
    - Implementation defined
    - Not user defined because it is a low-level concept and this is a high-level abstraction
  - Character encoding scheme
    - Specified by the Encoding parameter
    - There are 5 choices—any others *may* require using a different tool
  - Text Storage
    - Contiguous
    - Null terminated (embedded nulls are OK except for the zero-overhead version)
  - Size type
    - Both size and difference types are int
    - This is very deliberate: should be the fastest native type
    - If you need more characters, you probably need a different tool anyway

The Template Parameters

```
template<int ENCODING, int FIXED_SIZE, int GROW_TYPE, int GROW_INCREMENT>
class ustring;
```

- Encoding
  - This parameter dictates both the assumed encoding and the underlying data type

– ASCII	char	native 8 bit encoding (e.g. CP-1252)
– UCS2	wchar_t	native 16 bit encoding (e.g. UCS-2)
– UTF8	unsigned char	UTF-8 encoding
– UTF16	char16_t	UTF-16 encoding
– UTF32	char32_t	UTF-32 encoding

- Fixed Size
  - Specifies the size of the local (vs. heap) allocation in elements
  - Includes the null terminator
  - May be zero to indicate heap-only allocation
- Grow Type
  - Controls the management of memory and the size vs. speed tradeoff
  - ZERO_OVERHEAD, FIXED, LINEAR, EXPONENTIAL
- Grow Increment
  - Specifies the amount to grow for Linear and Exponential growth
  - Linear: capacity increases by the Grow Increment in elements
  - Exponential: capacity increases by 1 / Grow Increment

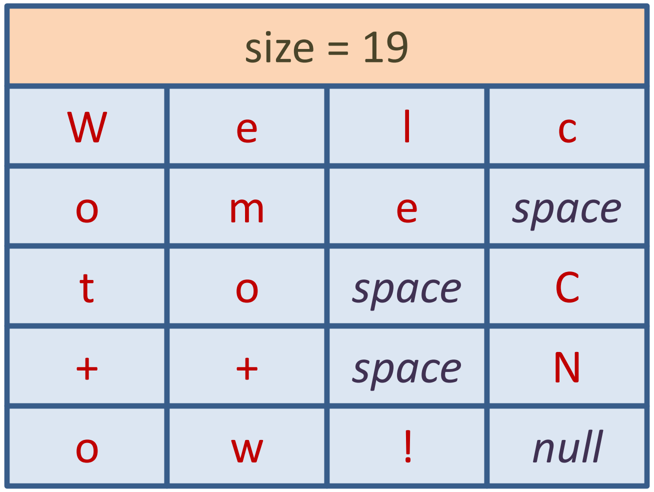
Memory Management

- Zero Overhead
  - Fixed size must be positive
  - Byte compatible with C arrays
  - No cached size
  - Capacity = fixed size
  - size(), end(), string_range() etc. are O(n)
  - Cannot have embedded nulls
  - Example: fixed size = 20, size = 19, capacity = 20

W	e	l	c
o	m	e	*space*
t	o	*space*	C
+	+	*space*	N
o	w	!	*null*

Memory Management

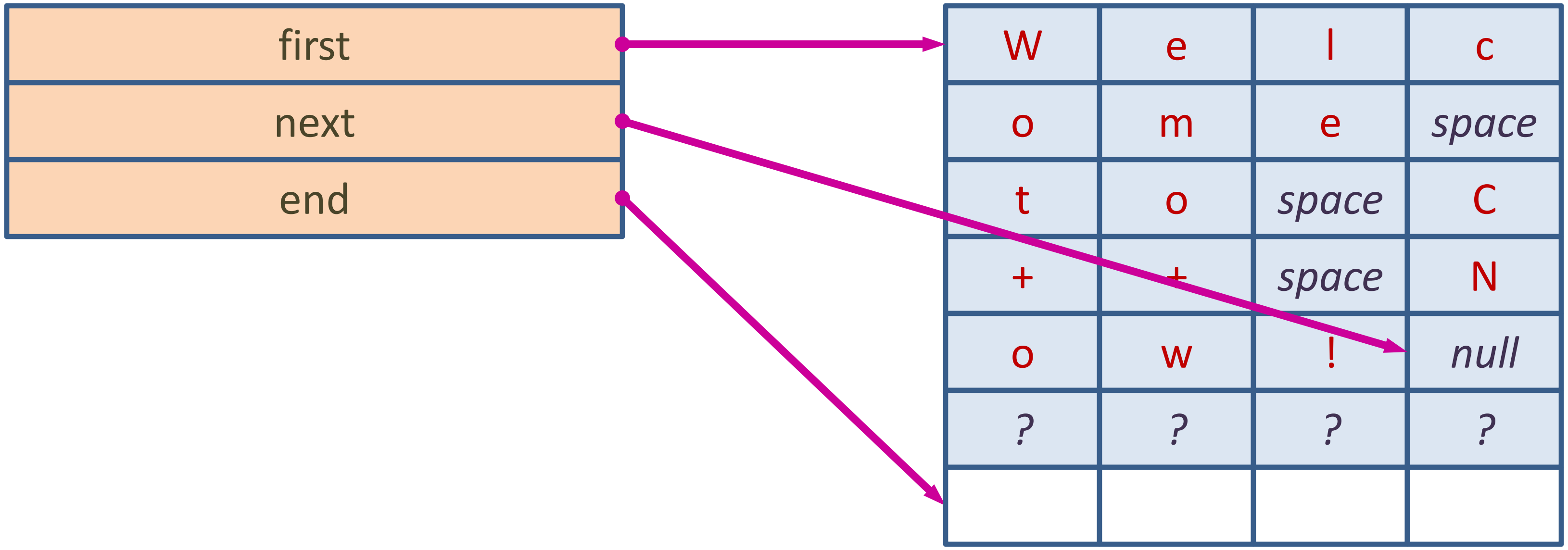
- Fixed
  - Fixed size must be positive
  - Includes a cached size
  - Capacity = fixed size
  - size(), end(), string_range() etc. are O(1)
  - Example: fixed size = 20, size = 19, capacity = 20



size = 19			
W	e	l	c
o	m	e	*space*
t	o	*space*	C
+	+	*space*	N
o	w	!	*null*

Memory Management

- Growable, zero fixed size
  - Includes cached size and capacity
  - Text elements are allocated on the heap
  - size(), end(), string_range() etc. are O(1)
  - Example: fixed size = 0, size = 19, capacity = 23



first

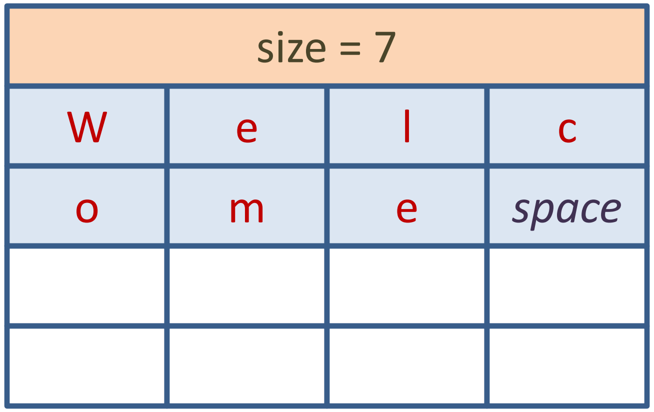
next

end

W	e	l	c
o	m	e	*space*
t	o	*space*	C
+	+	*space*	N
o	w	!	*null*
?	*?*	*?*	*?*

Memory Management

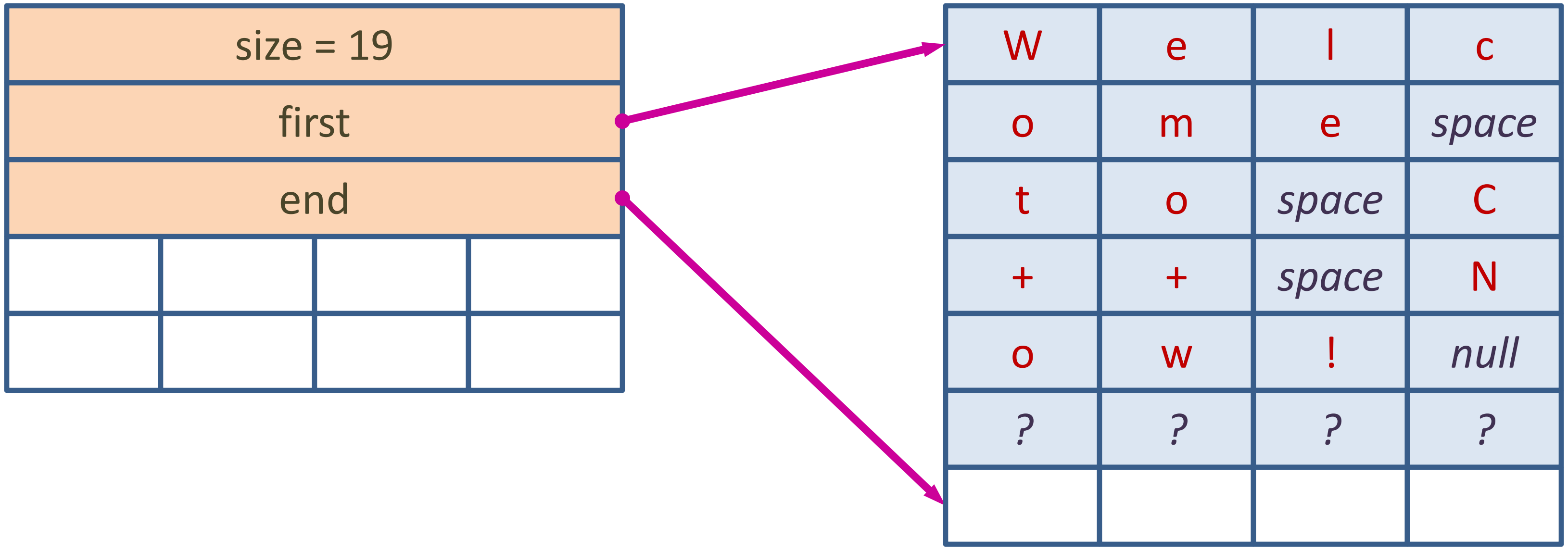
- Growable, positive fixed size
  - Includes cached size and capacity
  - Text elements are allocated locally or on the heap
  - size(), end(), string_range() etc. are O(1)
  - Example: fixed size = 16, size = 7, capacity = 15



size = 7			
W	e	l	c
o	m	e	*space*

Memory Management

- Growable, positive fixed size
  - Includes cached size and capacity
  - Text elements are allocated locally or on the heap
  - size(), end(), string_range() etc. are O(1)
  - Example: fixed size = 16, size = 19, capacity = 23



size = 19

first

end

W	e	l	c
o	m	e	*space*
t	o	*space*	C
+	+	*space*	N
o	w	!	*null*
?	*?*	*?*	*?*

Basic Members

- Constructors

```
ustring()
ustring(int count, char)
ustring(const char*)
ustring(string_range)
```

- Assignment

```
ustring& operator=(const char*)
ustring& operator=(string_range)
```

- Conversion

```
operator const char*() const
operator string_range<ENCODING>()
operator const_string_range<ENCODING>()
```

- Free function conversion

```
template<int SZ> ustring& ustring_cast(char (&a)[SZ])
```

Access Members

- Size

```
size_type size() const      excluding the null terminator
size_type capacity() const  excluding the null terminator
bool empty() const
bool heap() const
```

- Iterator access

```
char_type* begin()          const/non-const
char_type* last()           const/non-const
char_type* end()            const/non-const
etc…                        c versions
```

- Element access

```
char_type front()           const/non-const
char_type back()            const/non-const
char_type operator[](int i) const/non-const
char_type at(int i)         const/non-const
```

Insertion Members

- Append

```
ustring& operator+=( . . . . . )
ustring& operator<<( . . . . . )
```

- Insert

```
char_type* insert(int position, char_type)
char_type* insert(char_type* where, char_type)
char_type* insert(int position, string_range)
char_type* insert(char_type* where, string_range)
```

- Erase

```
void clear()
char_type* erase(int position)
char_type* erase(char_type* where)
char_type* erase(string_range)
```

Length Modifying Members

- Editing
  - Trim

    ```
    void trim(char_type char_to_remove)
    void trim(const char_type* chars_to_remove)
    void trim(string_range chars_to_remove)
    ```

  - Trim Front, Trim Back
  - Remove
    - Same as Trim but throughout the string
  - Replace
- Formatting
  - Format
    - printf vs. Python-like
    - Implemented as a variadic template rather than a variadic function
  - Field
    - Expand to given length
    - Text is positioned left, center, or right
- Encoding Conversions

Other Members

- Search
  - Find First, Find Last
- Stream
  - Operator <<
  - Operator >>

Ustring Examples

```
ustring<ASCII> us;
us << "Pi = " << precision(3.14159, 3) << " and UQ = " << 42;
cout << us;

Pi = 3.142 and UQ = 42
```

```
char buff[64] = "Welcome";                Welcome
auto& usc = ustring_cast(buff);
usc += '!';                               Welcome!
usc.insert(usc.last(), " to C++ Now");    Welcome to C++ Now!
to_upper(substr(usc, 0, 7));              WELCOME to C++ Now!
```

String Range

- Overview
  - The link between the ustring class and the string algorithms
  - Provides interoperability with other kinds of strings
  - Is often all you need
- Template Arguments

```
template<int ENC, bool CONST = false> struct string_range;
template<int ENC> using const_string_range = string_range<ENC, true>;
```

  - Encoding
    - The same meaning as for ustring
  - Const
    - True if this range refers to const data

String Range Members

- Constructors

```
string_range()
string_range(char_type*)
template<size_t SZ> string_range(char_type (&ar)[SZ])
string_range(const std::basic_string&)
```

- Content

```
operator bool()
bool empty()
size_type size()
```

- Iterator access

```
char_type* operator*()
char_type* begin()
char_type* last()
char_type* end()
```

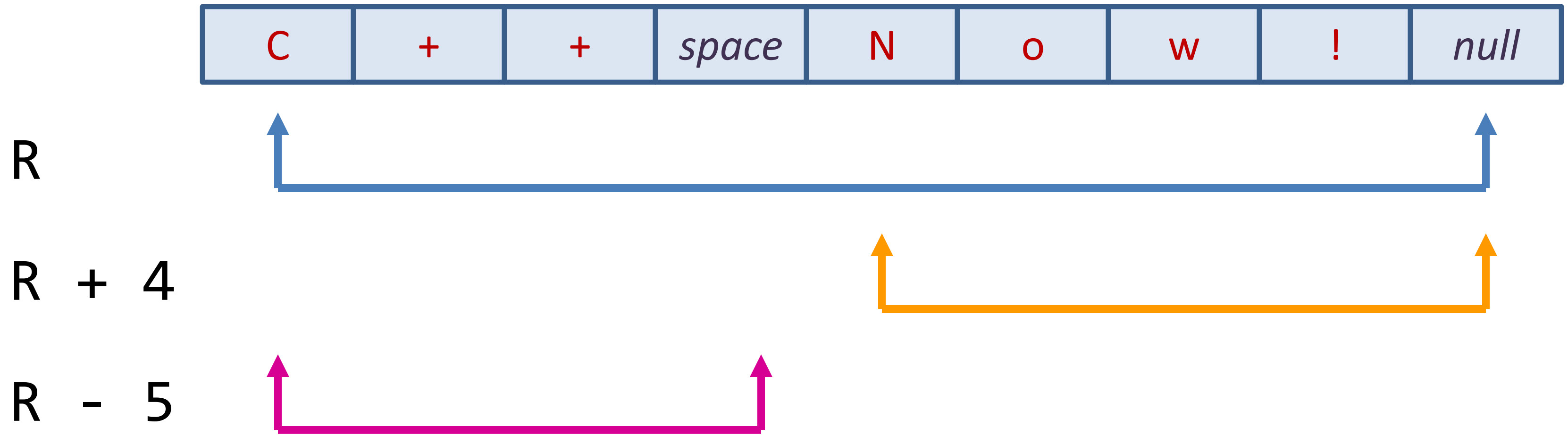
- Element access

```
char_type front()              const/non-const
char_type back()               const/non-const
char_type operator[](int i)    const/non-const
char_type at(int i)            const/non-const
```

String Range Members

- Shrink operations

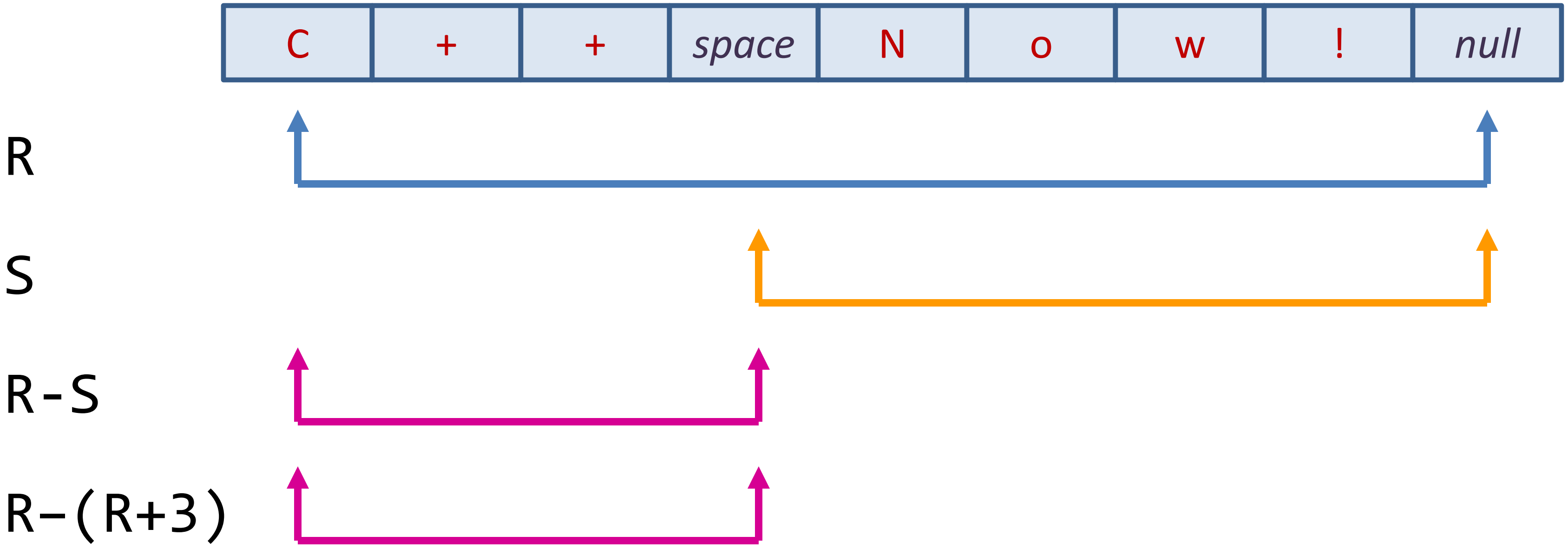
```
string_range& operator++()                    (not safe)
string_range& operator++(int)                 (not safe)
string_range& operator+=(int distance)
string_range operator+(string_range, int distance)
etc…
```



String Range Members

- Shrink operations

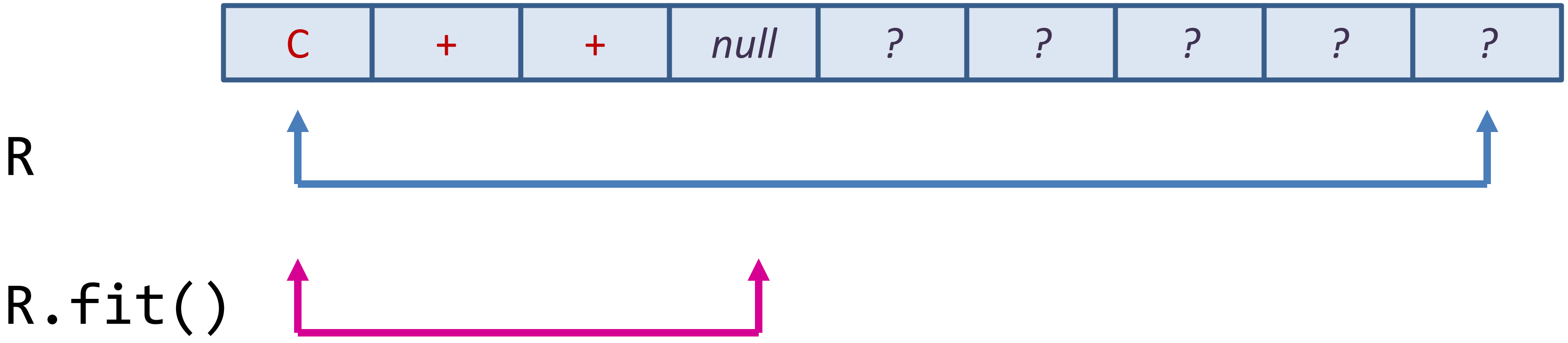
```
string_range& operator-=(string_range)
string_range operator-(string_range, string_range)
```



String Range Members

- Shrink operations

```
string_range& fit()
```



C	+	+	*null*	*?*	*?*	*?*	*?*	*?*

string_range Example

```
string_range<ASCII, true> r = "Welcome to C++ Now!";

for (; r; ++r)
   cout << *r;
```

```
Welcome to C++ Now!
```

Algorithms

- Goals
  - Composability
  - Compatibility
  - Convenience
  - Performance
- Design
  - Conceptually take a string_range and (usually) other arguments
  - Actually use TMP to generate a string_range from many types
  - Return
    - string_range
    - bool
  - May modify the target range

Non-modifying Algorithms

- All
  - Could also be called Make Range
- Substring
  - substr   From start to start + length
  - substrp   From start to stop
- Trim
  - Takes either char_type or a string_range to match
  - Defaults to white space
  - Trim Front
  - Trim Back
- Token
  - Takes a string_range& and advances it as each token is found
  - Returns a string_range that defines the token
  - Takes either char_type or a string_range to match
  - Non-destructive
- Divide
  - Same as Token, but includes the delimiter in the returned token
  - Nice for breaking text into lines

substr

```
template<typename T>
typename string_range_traits
<typename std::remove_reference<T>::type>::type
substr(T&& t, int start, int length = std::numeric_limits<int>::max())
{
   typename string_range_traits
   <typename std::remove_reference<T>::type>::type
   str(std::forward<T>(t));

   str += start;
   str -= str.size() - length;

   return str;
}
```

substrp

```
template<typename T>
typename string_range_traits
<typename std::remove_reference<T>::type>::type
substr(T&& t, int start, int length = std::numeric_limits<int>::max())
{
   typename string_range_traits
   <typename std::remove_reference<T>::type>::type
   str(std::forward<T>(t));

   str -= str.size() - stop;
   str += start;

   return str;
}
```

substr Calls

```
cout << substr("Maroon Bells", 7, 5) << endl;

char buff[64] = "Maroon Bells";
cout << substr(buff, 7, 5) << endl;

auto c = "Maroon Bells";
cout << substr(c, 7, 5) << endl;

const string s("Maroon Bells");
cout << substr(s, 7, 5) << endl;

wstring ws(L"Maroon Bells");
wcout << substr(ws, 7, 5) << endl;

string_range<ASCII, true> sr = "Maroon Bells";
cout << substr(sr, 7, 5) << endl

ustring<ASCII> us("Maroon Bells");
cout << substr(us, 7, 5) << endl;
```

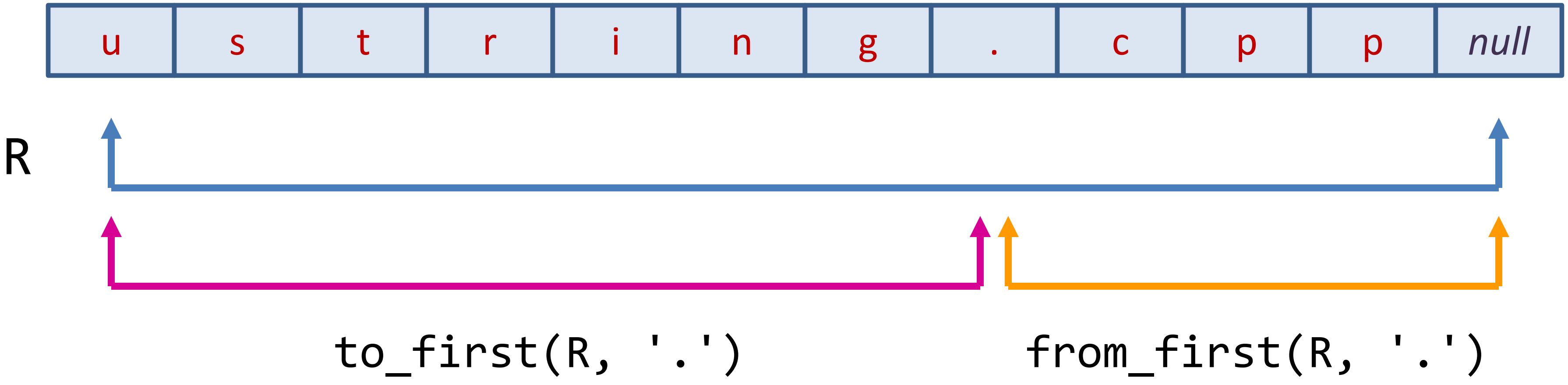
token Call

```
auto data = all("Welcome to C++ Now! in Aspen, CO");
while (data)
   cout << token(data, ' ') << endl;
```

```
Welcome
to
C++
Now!
in
Aspen,
CO
```

Non-modifying Algorithms

- To First, From First
  - Takes either char_type or a string_range to search for
  - To in the sense of "up to", from in the sense of "starting from"
  - so to_first(R, X) plus from_first(R, X) equals R
- To Last, From Last
- To First Not, From First Not
- To Last Not, From Last Not



u	s	t	r	i	n	g	.	c	p	p	*null*

R

`to_first(R, '.')`

`from_first(R, '.')`

Modifying Algorithms

- Copy
  - Takes two string_ranges, source and destination
  - Only works within one encoding
  - Safe copy
- Replace
  - Takes two characters, replaces all occurrences of one with the other
  - Only works within one encoding
  - For cross-encoding replace, the ustring member is required because of length changes
- Reverse
  - Reverses the range in place
- To Upper / To Lower
  - Makes changes in place
  - Only works within one encoding
  - For cross-encoding replace, the ustring member is required because of length changes

Comparison Algorithms

- Equal, Equal NC
  - Binary equality
  - NC uses simple (fast) conversion
- Less, Less NC, Greater, Greater NC
  - Binary comparison
- Compare, Compare NC
  - Binary comparison
  - Returns -1, 0, 1
- Unicode and Locale
  - Support for more intelligent comparison

Extract File Title

```
auto path = all("D:\\Code\\Ustring\\Source\\Heaponly.h");
cout << (from_last(path - from_last(path, '.'), '\\') += 1);
```

```
Heaponly
```

```
cout << to_last(from_last(path, '\\') += 1, '.');
```

```
Heaponly
```

Algorithm Composition

```
cout <<
  to_first(
    trim_front(
      from_first(
        from_first("Colorado rocky mountain high", 'k'), ' '
      )
    ), ' '
  );
```

```
mountain
```

Switch on File Type (MFC)

```
CString ext(lpszPathName);
int ext_len = ext.ReverseFind('.');
ext = ext.Right(ext_len == -1 ? 0 : ext.GetLength() - (ext_len + 1));

if (ext.CompareNoCase("top") == 0)       // If this is a TOP file.
{
}
else if (ext.CompareNoCase("rr") == 0)   // If this is an RR file.
{
}
```

Switch on File Type (STL)

```
string ext(lpszPathName);
ext = ext.substr(ext.find_last_of('.') + 1, ext.npos);

if (_stricmp(ext.c_str(), "top") == 0)     // If this is a TOP file.
{
}
else if (_stricmp(ext.c_str(), "rr") == 0) // If this is an RR file.
{
}
```

Switch on File Type (ustring)

```
auto ext = ustr::from_last(lpszPathName, '.') += 1;

if (equal_nc(ext, "top"))        // If this is a TOP file.
{
}
else if (equal_nc(ext, "rr"))    // If this is an RR file.
{
}
```

Interoperability with std::string

```
std::string boostcon("BoostCon");
ustring<ASCII> cppnow("C++ Now!");

cout << greater(cppnow, boostcon);
```

```
true
```

The Discussion

- Ground rules
  - We have 45 minutes and *n* people, so each person gets *t* = 45/*n*
    - Once everyone has been heard, people can have second turns
    - Show of hands who might like to participate so we can calculate *t*
  - The goal is to get lots of good ideas out on the table
    - We do not need to solve every problem
    - We do not need to convince anyone of anything
    - We do not need to reach consensus
- Focus
  - Big picture
  - Architecture
  - API design
  - Use cases
- Examples
  - I can show some real code examples as we go

Acknowledgements and Thanks

- Beman Dawes
  - Reviewed the library design in depth and made many helpful suggestions about the library and this presentation
- Jeffrey Yasskin
  - Presented proposals to the C++ Committee on string_ref and ranges, discussed this library with me, and helped to convince me of the value of the range-based design
- David Abrahams
  - Discussed the idea with me and encouraged me to give a presentation at this early stage in the library's development
- You
  - For all the great ideas you are about to contribute