Who am I?

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Office Hours:
Thursdays, 10:30-12:00 PM (Zoom)
… or by appointment

https://courses.engr.illinois.edu/cs225/sp2022/info/office-hours/
Who are you?

Take a moment to introduce yourself in chat!

(Your name, a hobby you enjoy, and one thing you hope to get out of this class)

https://campuswire.com/c/G5A2320D7
What is this class about?

String Algorithms and Data Structures

Exact string matching

Compressed self-indexes

Inexact pattern matching

Query: 161 atatcaccacgtcaaaggtgactccaactcca---ccactccccccccccctttt

Sbjct: 481 atatcaccacgtcaaaggtgactccaact-tattgatagttttttatgttt
What will you get out of this class?

Understand fundamental string algorithms

Experience applying data structures, algorithms, and algorithm design principles to real world problems

Justify implementation choices based on theoretical or practical considerations

Build a foundation for future data science projects
Course Webpage

https://courses.engr.illinois.edu/cs225/sp2022/pages/honors.html

All course information and links can be found here!

Zoom
Mediaspace recordings
Campuswire
Moodle
Syllabus
Syllabus

Please read — many important topics:

Course Goals & Topics

Course Expectations

Grading

Commitments to Diversity, Equity, Inclusion

Commitments to Mental Health

Ethics and Academic Integrity Policies
Course Expectations

Weekly assignments (1000 points):

Small assignments (~ 2-3 hours / week)

No lab sections

Must submit your own work

Two 24-hour extensions by request

The lowest homework grade will be dropped
Course Expectations

Class participation (0 points):

No attendance grades

Ask questions (synchronously or asynchronously)

Participate in breakout rooms and polls
Grading

Total points in class: 1000

A: [900, 1000]

B: [800, 900)

C: [700, 800)

D: [600, 700)

F: [0, 600)
Mental Health

This class should be low-stress, light work-load.
UIUC offers a variety of confidential services:

**Counseling Center:** 217-333-3704
610 East John Street Champaign, IL 61820

**McKinley Health Center:** 217-333-2700
1109 South Lincoln Avenue, Urbana, Illinois 61801
Diversity, Equity, and Inclusion

“If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of…”

Staff (CAs and TAs for CS 225)

Faculty (Myself or Carl)

BART (https://bart.illinois.edu/)

For more details about the BART response policy, refer to https://bart.illinois.edu/procedures/
Learning Objectives

Review fundamentals of strings

Introduce exact pattern matching problem
What is a string?

*String* $S$ is a finite sequence of characters

Characters are drawn from alphabet $\Sigma$, usually assumed finite

Nucleic acid alphabet: $\{A, C, G, T\}$


What are some other alphabets we could use?
What is a string... in C++?

**char**: 1-byte (8-bit) character encoding [ASCII 256]

**std::string**: uses `char` alphabet (by default), has significant operation support

```cpp
#include <string>
#include <iostream>

int main() {
    char c[] = "Hello World";
    std::string str = "Hello World";
    return 0;
}
```

Fundamental operations

Math

Strings
Fundamental string operations

“How efficient is my algorithm at searching for a given pattern $P$?”

“How much memory do I need to allocate for this text file?”
Fundamental string operations

**Size** of $S$, $|S|$: The number of characters in $S$.

$S = \text{“How big?”}$

$|S| = \text{?}$
Fundamental string operations

**Size** of $S$, $|S|$: The number of characters in $S$.

$S =$ “How big?”

$|S| = 8$
Fundamental string operations

**Size** of $S$, $|S|$: The length of $S$ (in terms of bytes).

$S$.length()
Fundamental string operations

“Is this book about data structures?”

“Is this student enrolled at UIUC?”
**Fundamental string operations**

$S$ **equals** $T$ if each character, in order, is the same

$S == T$

```cpp
#include <string>
#include <iostream>

int main() {
    std::string S = "Thing 1";
    std::string T = "Thing 1";

    if (S == T){
        std::cout << "S == T" << std::endl;
    } else {
        std::cout << "S != T" << std::endl;
    }
    return 0;
}
```
Fundamental string operations

S equals T if each character, in order, is the same

S == T

```cpp
#include <string>
#include <iostream>

int main() {
    char S[] = "Thing 1";
    char T[] = "Thing 1";

    if (S == T){
        std::cout << "S == T" << std::endl;
    } else {
        std::cout << "S != T" << std::endl;
    }
    return 0;
}
```
### Fundamental string operations

#### Reads

<table>
<thead>
<tr>
<th>Read 1</th>
<th>Read 2</th>
<th>Read 3</th>
<th>Read 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTATGCACCGGATAG</td>
<td>TATGTCGCAGTATCT</td>
<td>CACCCTATGTCGACG</td>
<td>GAGACGCTGGAGCCG</td>
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<tr>
<td>TAGCATTGCGAGACG</td>
<td>GGTATGCACCGGATA</td>
<td>TGGAGCCGGAGCAACC</td>
<td>CGCTGGAGCCGGAGC</td>
</tr>
<tr>
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<td>CGCGATAGCATTTCG</td>
<td>GCAATGCGAGACGCT</td>
<td>CCTATGTCGCACTAT</td>
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<td>GTATCTGTCTTTTGAT</td>
<td>CCTCATCCTATTATT</td>
</tr>
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<td>CAATATTCGATCATG</td>
<td>GATCACAGGTCTATC</td>
<td>ACCCTATTACCCACT</td>
</tr>
<tr>
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<td>CGTCTGGGGGGTATG</td>
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</tr>
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<td>TATTTATGCACCTA</td>
<td>CCACTACCGGGAGCCT</td>
</tr>
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<td>CCGAGACGCTGGAGC</td>
<td>CTATCACCTATTAA</td>
<td>CTGTCTTTGATTCCCT</td>
<td>ACTACCGGGAGCTCT</td>
</tr>
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<td>GCACACCTAGTCAAT</td>
<td>GTCTGGGGGGTATGC</td>
<td>AGCCGGAGCACCTA</td>
</tr>
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<td>GACGTGGGAGCCGGGA</td>
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<td>GTATCTGTCTTTTGAT</td>
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<td>GATCACAGGTCTATC</td>
<td>ACCCTATTACCCACT</td>
</tr>
<tr>
<td>CACGGGAGCTCTTCCA</td>
<td>TGCATTGGTATTTT</td>
<td>CGTCTGGGGGGTATG</td>
<td>CACGCAGTAGCATTT</td>
</tr>
</tbody>
</table>

#### Genome

CGTCTGGGGGGTATGCACCGGATAGCATTTGCGAGACGCTGGGAGCCGGAGCACCCTATGTCGCACTATCTGCTTTTGATTCCCTG
Fundamental string operations

**Concatenation** of $S$ and $T$: characters of $S$ followed by characters of $T$

$S = \text{“Beep”}$ \hspace{1cm} $T = \text{“Boop”}$

What is the string $ST$?

What is the string $T$S?
Fundamental string operations

**Concatenation** of $S$ and $T$: characters of $S$ followed by characters of $T$

$S + T$

```cpp
#include <string>
#include <iostream>

int main() {
    std::string S = "Beep";
    std::string T = "Boop";

    std::cout << S + T << std::endl;
    std::cout << T + S << std::endl;
    std::cout << S + '$' + T << std::endl;
    std::cout << T + '$' + S << std::endl;
}
```
Google’s stated mission, “to organize the world’s information and make it universally accessible and useful,” could not better capture the immense ambition of modern society for gathering all kinds of data and putting them to use to improve our lives. We are collecting not only huge amounts of data from the physical world (astronomical, climatological, geographical, biological), but also human-generated data (voice, pictures, music, video, books, news, Web contents, emails, blogs, tweets) and society-based behavioral data (markets, shopping, traffic, clicks, Web navigation, likes, friendship network).
Fundamental string operations

S is a **substring** of T if there exists (possibly empty) strings u and v such that $T = uSv$

A **substring** is a sequence of characters (a string) contained within another string

$S$: pepper

$T$: I_like_pepperoni_pizza
Fundamental string operations

A **substring** of $S$ is a string occurring inside $S$

$S$.**substr**(size_t pos, size_t len)

```cpp
#include <string>
#include <iostream>

int main() {
    std::string T = "Hello my name is ";
    std::cout << T.substr(1,4) << std::endl;
    return 0;
}
```
Fundamental string operations

$S$ is a prefix of $T$ if there exists a string $v$ such that $T = Sv$

A prefix is a substring $T = uSv$ where $u = ""$

$$T: \textcolor{red}{G T T A T A G C T G A T} \quad \textcolor{blue}{G T T A T A G C T G A T}$$

$$S, \quad v$$
Fundamental string operations

S is a **prefix** of T if there exists a string v such that $T = Sv$

$T: \text{G T T A T A G C T G A T}$
Fundamental string operations

$S$ is a **prefix** of $T$ if there exists a string $v$ such that $T = Sv$

$T$: **Pattern matching**

- **Patter** ✓
- **matching** ✗
- **Patrick** ✗
Fundamental string operations

S is a *suffix* of T if there exists a string u such that $T = uS$

A *suffix* is a substring $T = uSv$ where $v = "\"$

\[
T: \text{GTTATAGCTGAT}
\]

\[
\text{GTTATAGCTGAT}
\]

\[
\text{u} \quad \text{S}
\]
Fundamental string operations

S is a **suffix** of T if there exists a string u such that \( T = uS \)

\[ T: \text{G T T A T A G C T G A T} \]
Fundamental string operations

S is a suffix of $T$ if there exists a string $u$ such that $T = uS$

$T$: Pattern matching

- ing: ✓
- tern: ✓
- ring: ✓
Fundamental string operations

Size, $|S|$

Equals, $S == T$

Concatenation, $ST$

Substring, $uSv$

Size, $|S|$

Equals, $S == T$

Concatenation, $S + T$

Substring, $S.substr(pos, len)$
Exact Pattern Matching

Pattern, $P$  Text, $T$

Find instances of $P$ in $T$

‘instances’: An exact, full length copy
Exact Pattern Matching

Find places where pattern $P$ occurs as a substring of text $T$. Each such place is an occurrence or match.

$P$: word

$T$: There would have been a time for such a word

Alignment 1: word

Alignment 2: word

Not a match! Match!

**Alignment**: a way of putting $P$’s characters opposite $T$’s. May or may not correspond to a match.
Exact Pattern Matching

What’s a simple algorithm for exact matching?

P: word

T: There would have been a time for such a word
word word word word word word word word word word word
word word word word word word word word word word word
word word word word word word word word word word word
word word word word word word word word word word word
word word word word word word word word word word word
word word word word word word word word word word word

Try all possible alignments. For each, check if it matches. This is the *naïve algorithm*.
Assignment 1: a_naive

Learning Objective:

Conceptualize exact pattern matching w/ naïve search

Demonstrate understanding of fundamental operations

Due: January 31st 11:59 PM

Think about as you code: is naïve search a good solution?
End-of-class brainstorm

How can we improve the naïve algorithm?

... if you have infinite space?

... if I tell you the pattern ahead of time?

... if I tell you the text ahead of time?