Indexed Search Tree (Trie)

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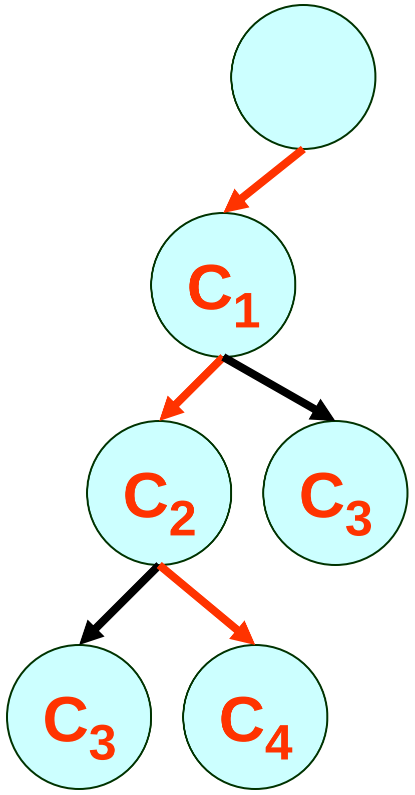
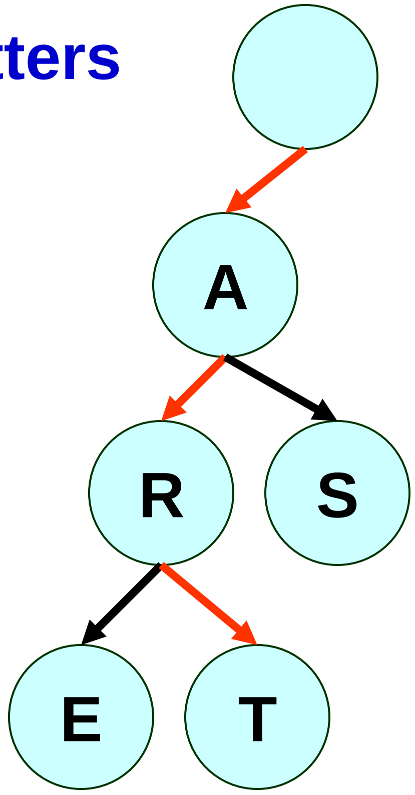
Indexed Search Tree (Trie)

- Special case of tree
- Applicable when
  - Key C can be decomposed into a sequence of subkeys C_1, C_2, … C_n
  - Redundancy exists between subkeys
- Approach
  - Store subkey at each node
  - Path through trie yields full key
- Example
  - Huffman tree



Tries

- Useful for searching strings
  - String decomposes into sequence of letters
  - Example
    - "ART" ⇒ "A" "R" "T"
- Can be very fast
  - Less overhead than hashing
- May reduce memory
  - Exploiting redundancy
- May require more memory
  - Explicitly storing substrings



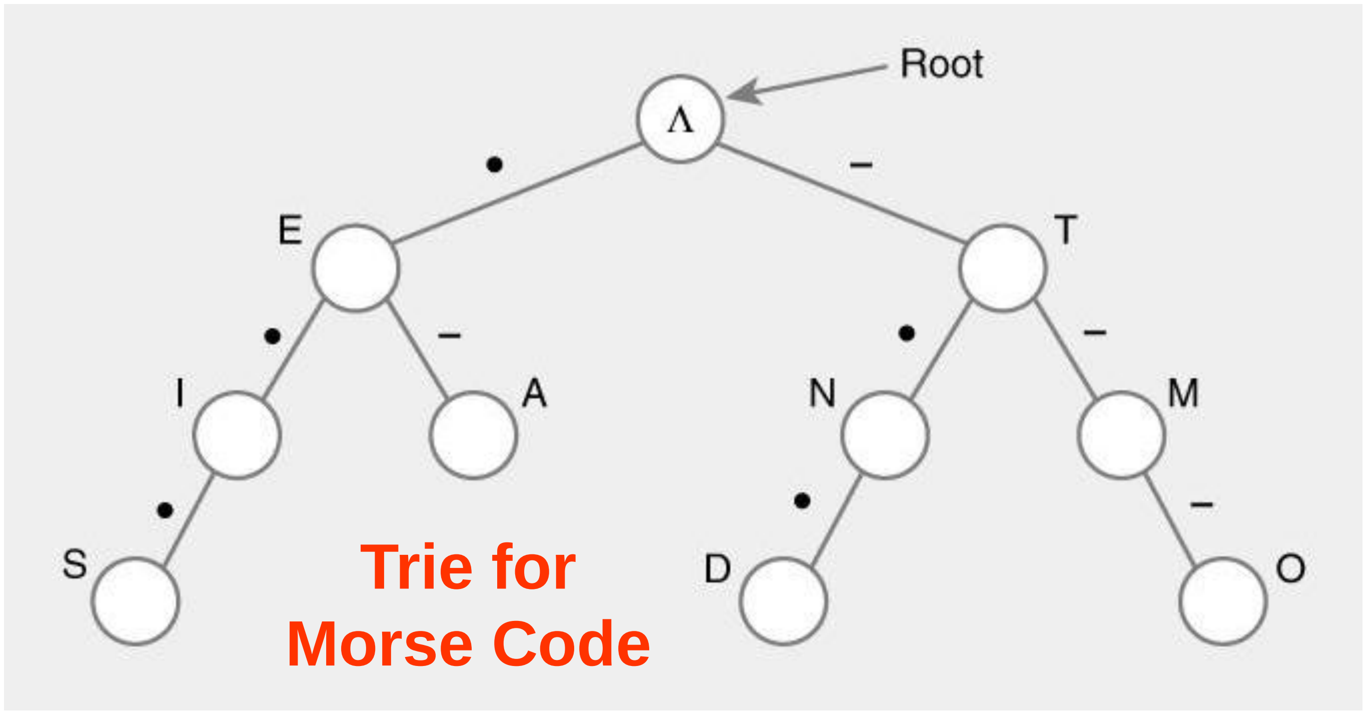
"ART"

Types of Tries

- Standard
  - Single character per node
- Compressed
  - Eliminating chains of nodes
- Compact
  - Stores indices into original string(s)
- Suffix
  - Stores all suffixes of string

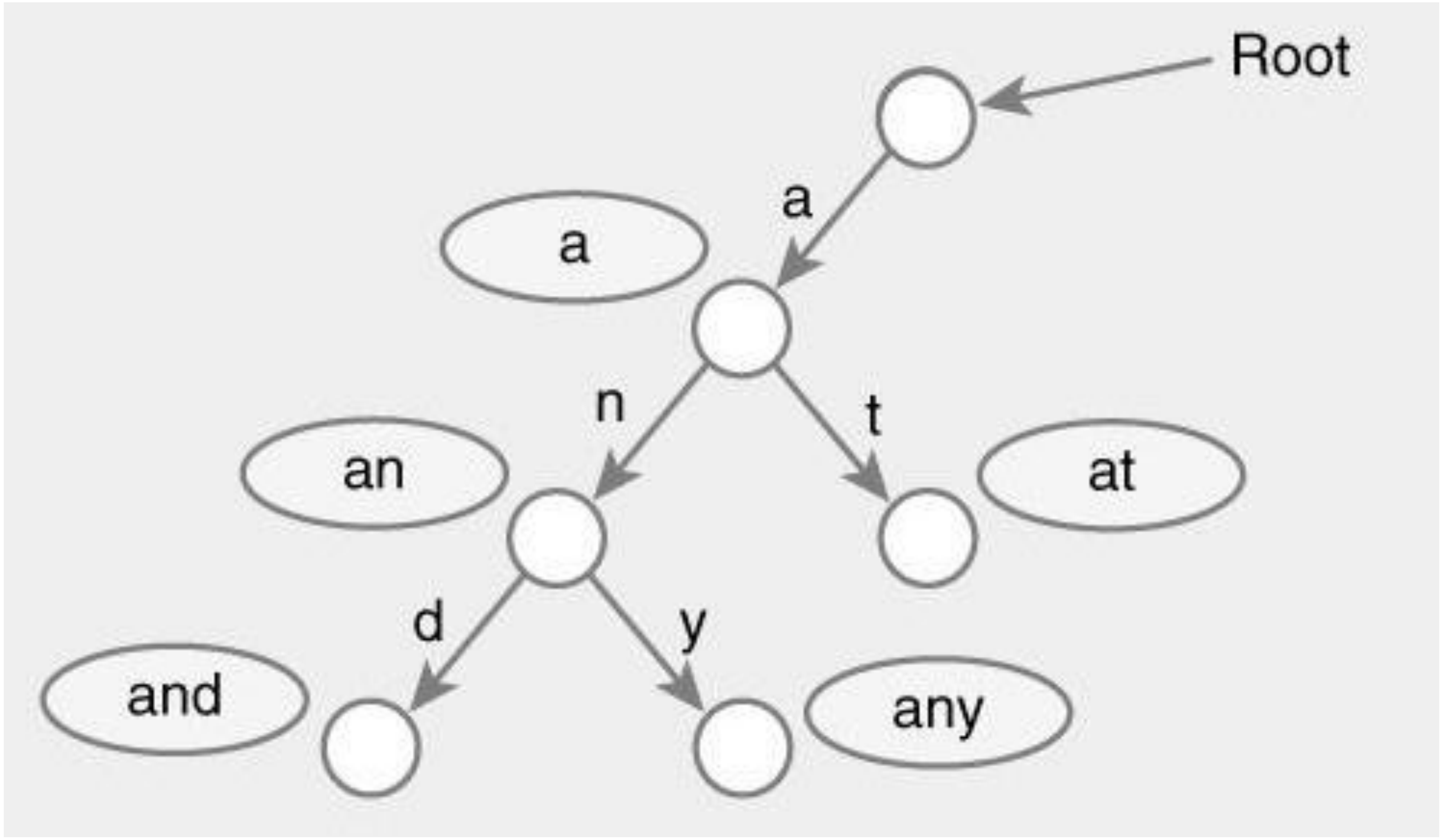
Standard Tries

- Approach
  - Each node (except root) is labeled with a character
  - Children of node are ordered (alphabetically)
  - Paths from root to leaves yield all input strings



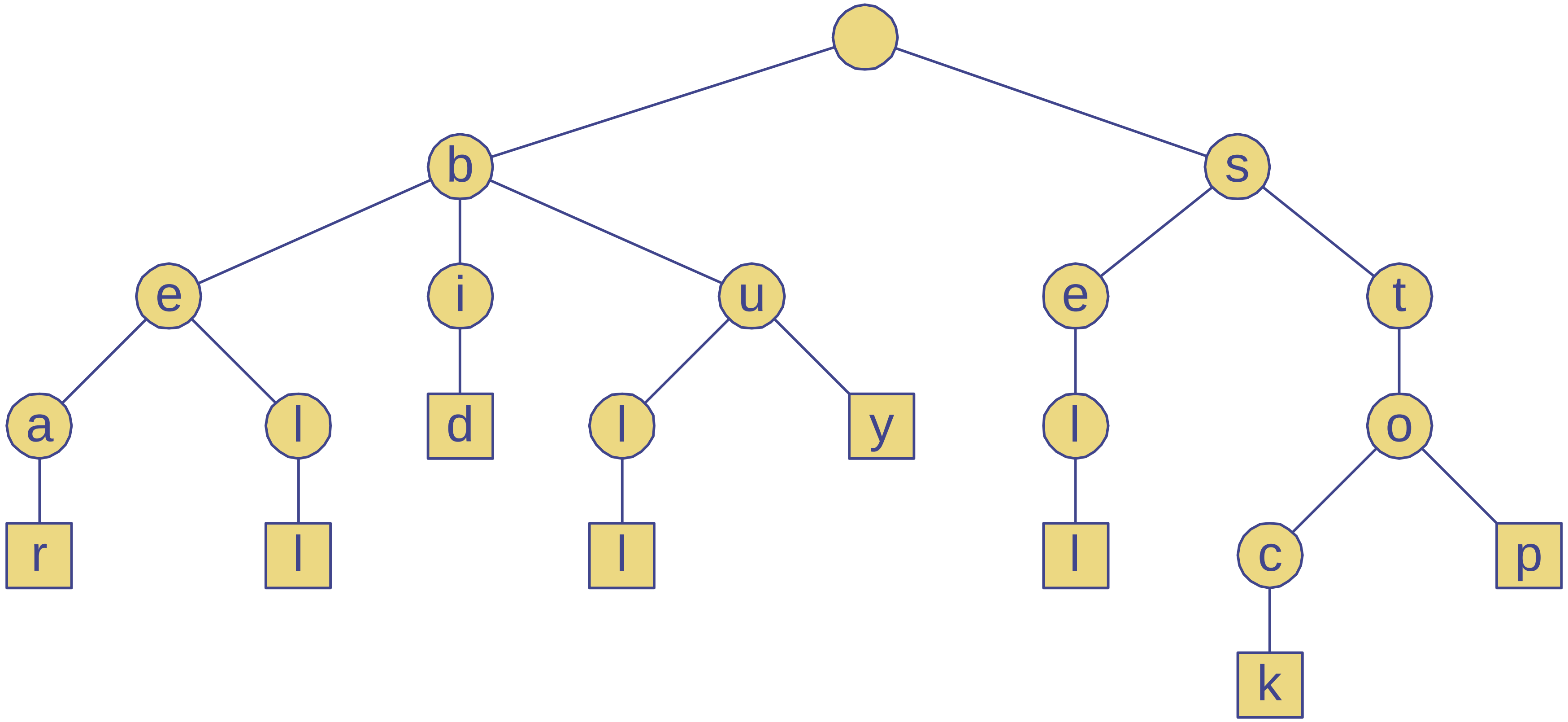
Standard Trie Example

- For strings
  - { a, an, and, any, at }



Standard Trie Example

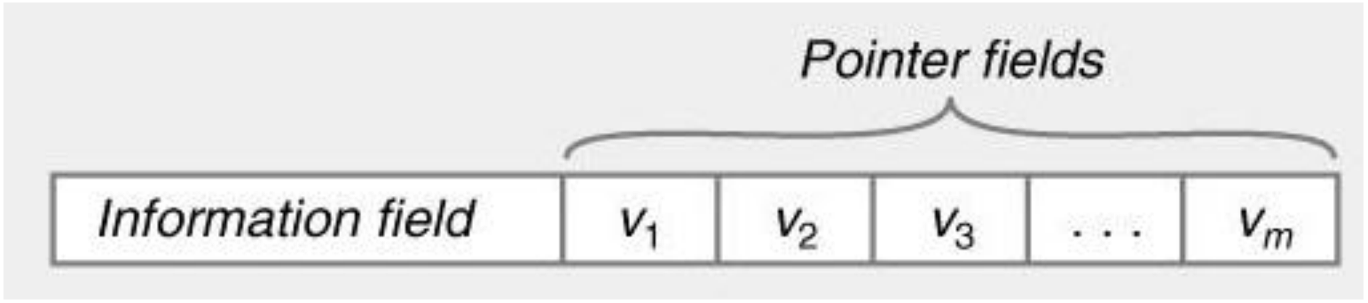
- For strings
  - { bear, bell, bid, bull, buy, sell, stock, stop }



Standard Tries

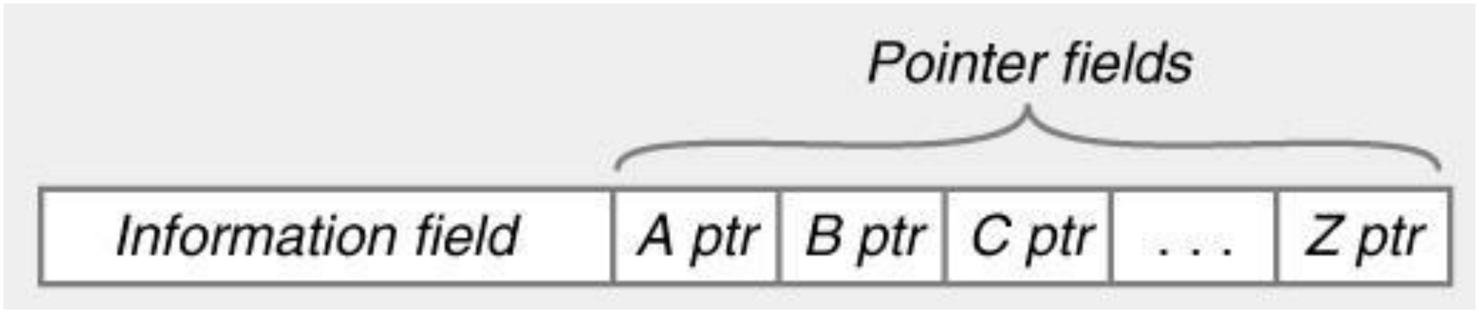
- Node structure
  - Value between 1…m
  - Reference to m children
    - Array or linked list
- Example

```
Class Node {
    Letter value;         // Letter V = { V1, V2, … Vm }
    Node child[ m ];
}
```



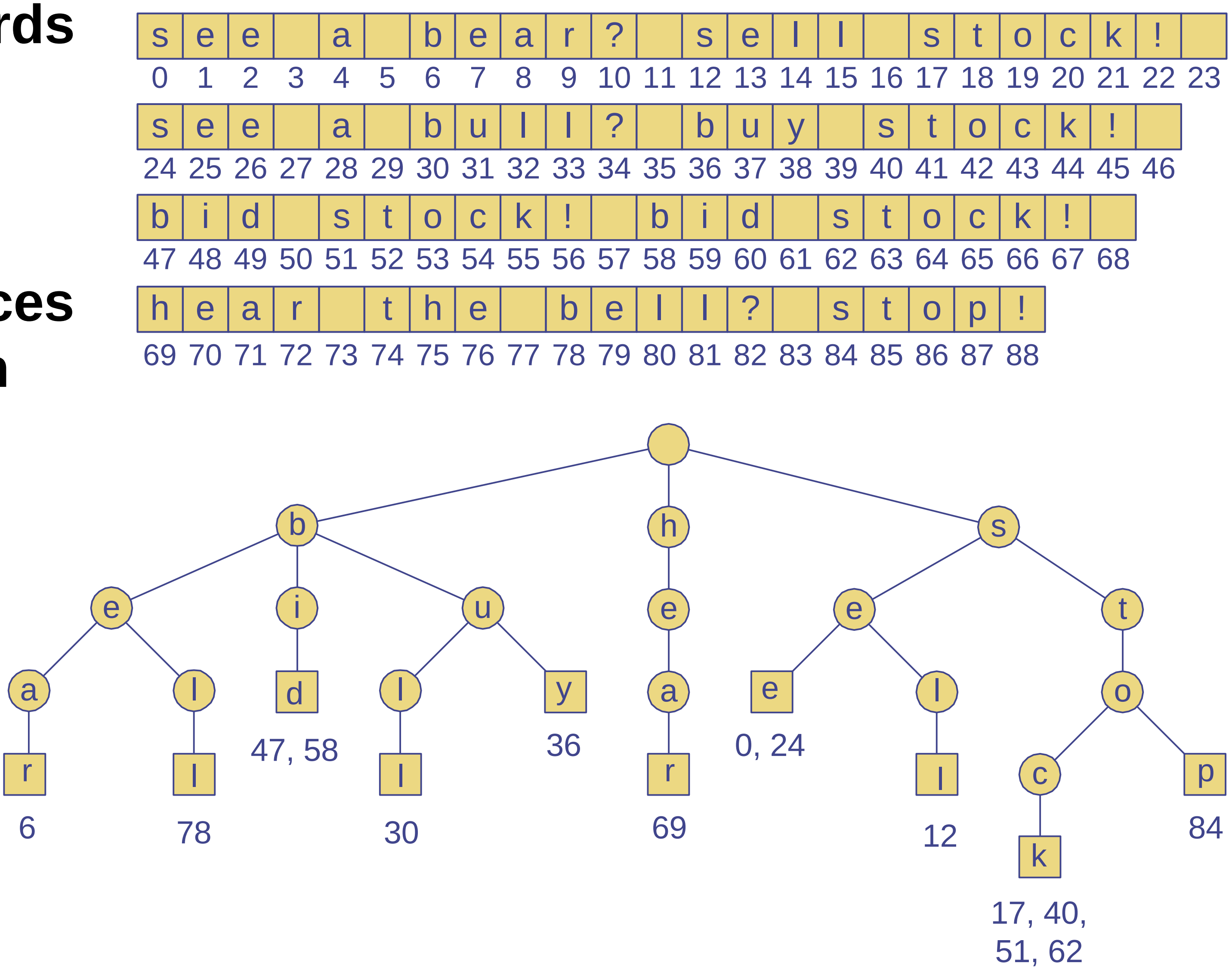
Standard Tries

- Efficiency
  - Uses O(n) space
  - Supports search / insert / delete in O(d×m) time
  - For
    - n total size of strings indexed by trie
    - d length of the parameter string
    - m size of the alphabet



Word Matching Trie

- **Insert words into trie**
- **Each leaf stores occurrences of word in the text**

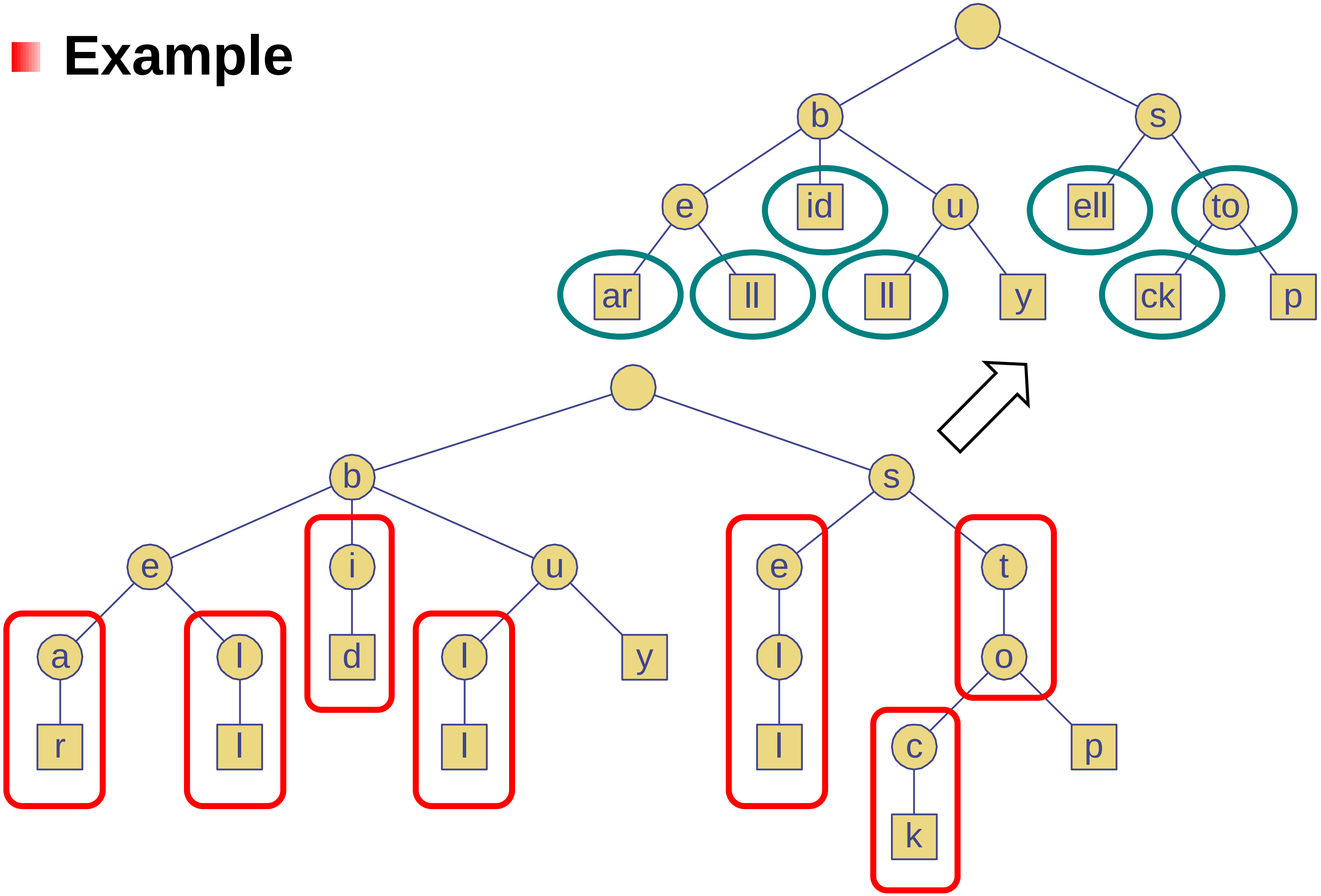


Compressed Trie

- Observation
  - Internal node v of T is redundant if v has one child and is not the root
- Approach
  - A chain of redundant nodes can be compressed
    - Replace chain with single node
    - Include concatenation of labels from chain
- Result
  - Internal nodes have at least 2 children
  - Some nodes have multiple characters

Compressed Trie

- **Example**

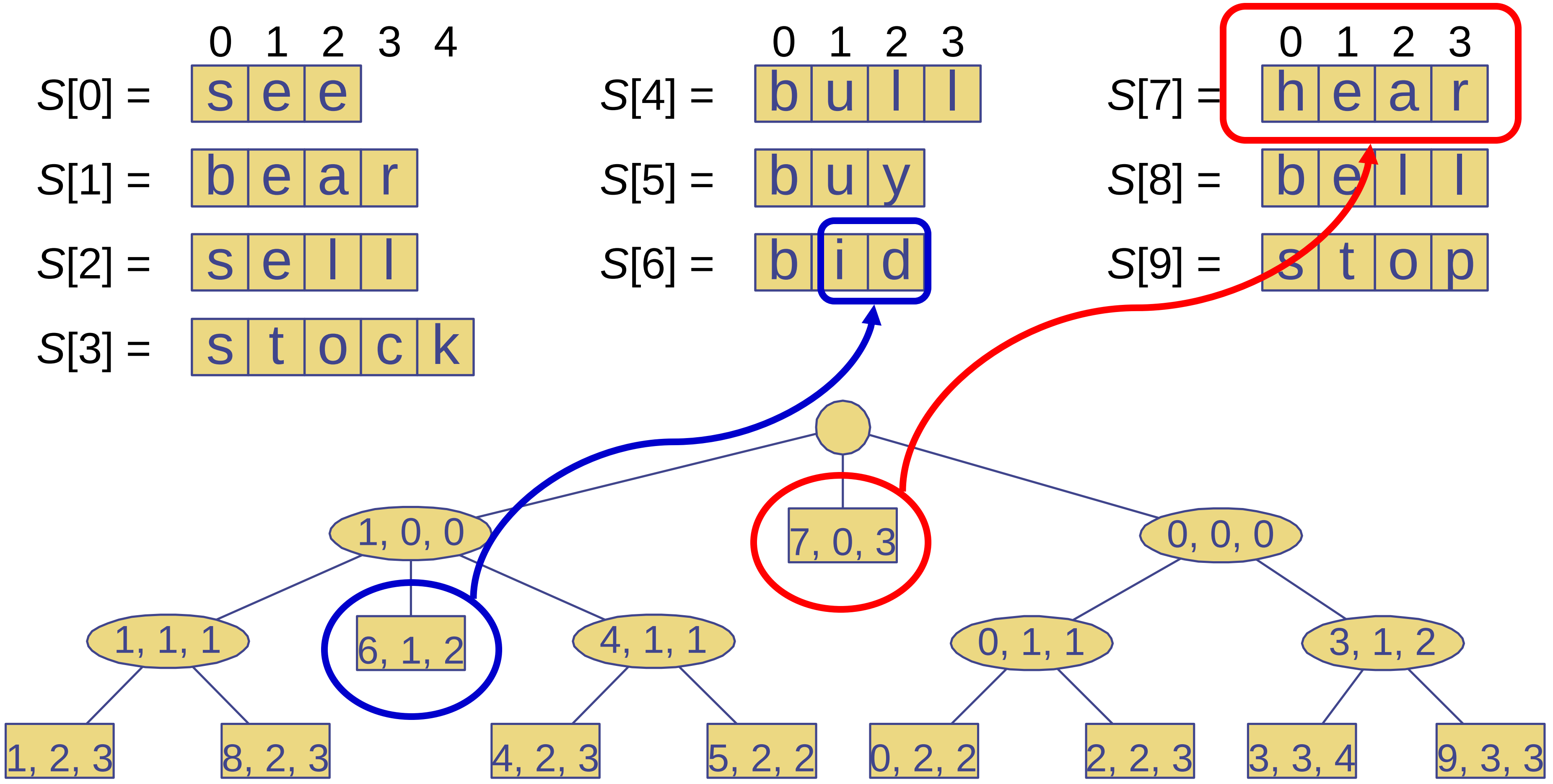


Compact Tries

- Compact representation of a compressed trie
- Approach
  - For an array of strings S = S[0], … S[s-1]
  - Store ranges of indices at each node
    - Instead of substring
  - Represent as a triplet of integers (i, j, k)
    - Such that X = s[i][j..k]
  - Example: S[0] = “abcd”, (0,1,2) = “bc”
- Properties
  - Uses O(s) space, where s = # of strings in the array
  - Serves as an auxiliary index structure

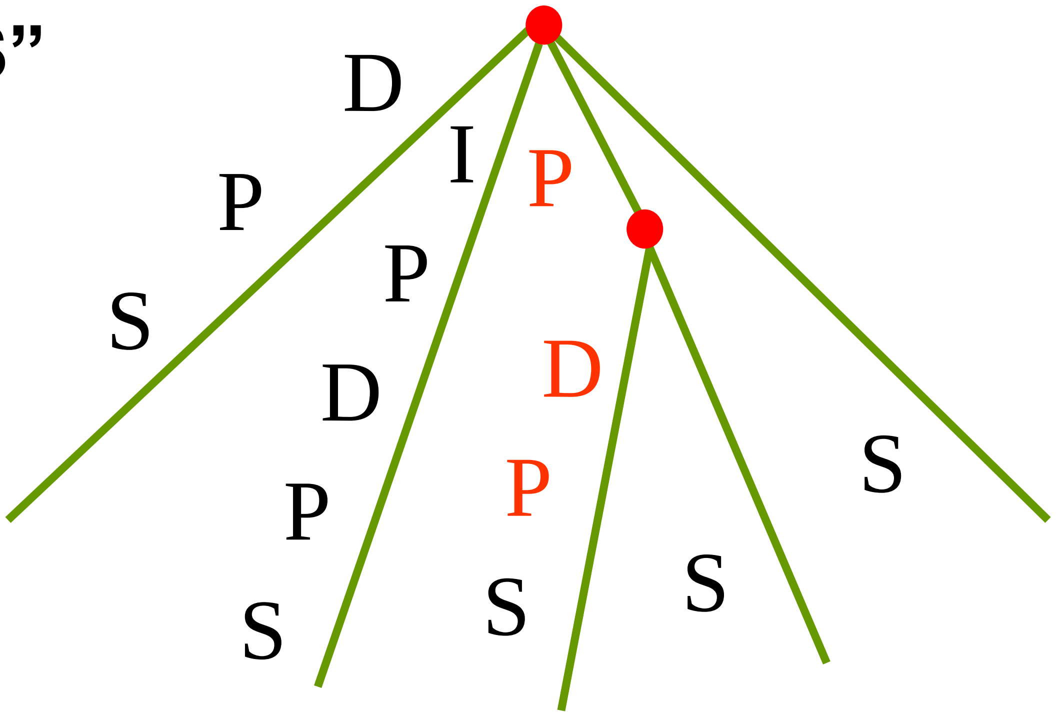
Compact Representation

- **Example**



Suffix Trie

- Compressed trie of all suffixes of text
- Example: “IPDPS”
  - Suffixes
    - IPDPS
    - PDPS
    - DPS
    - PS
    - S



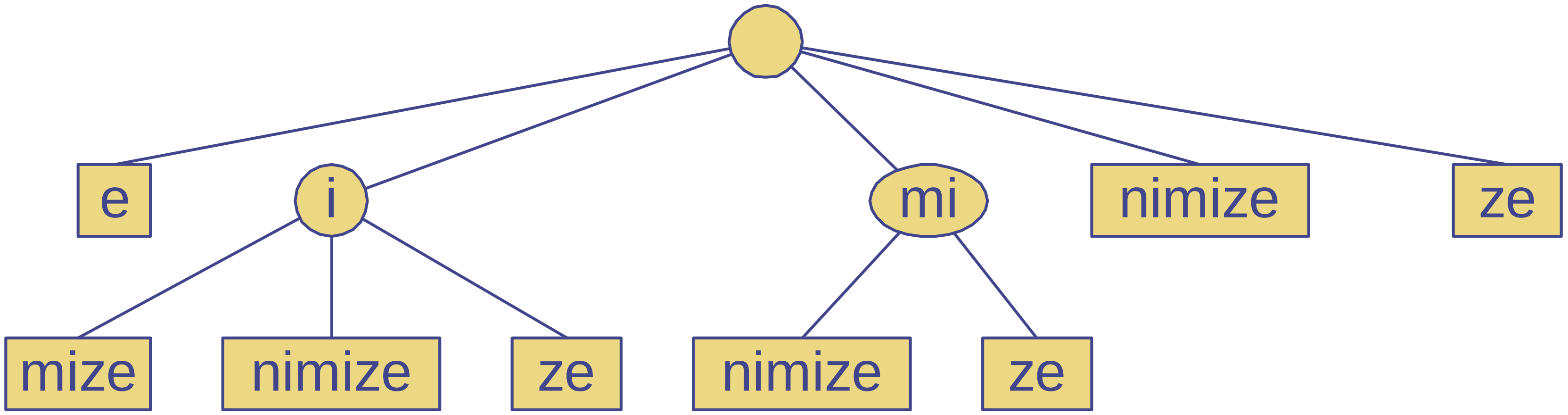
- Useful for finding pattern in any part of text
  - Occurrence ⇒ prefix of some suffix
  - Example: find PDP in IPDPS

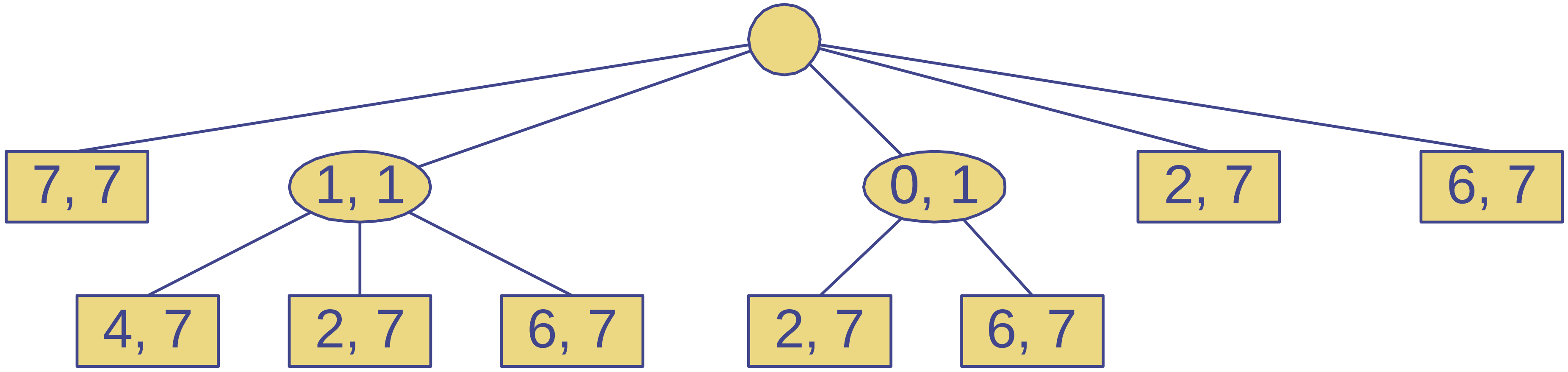
Suffix Trie

- Properties
  - For
    - String X with length n
    - Alphabet of size m
    - Pattern P with length d
  - Uses O(n) space
  - Can be constructed in O(n) time
  - Find pattern P in X in O(d×m) time
    - Proportional to length of pattern, not text

Suffix Trie Example

m	i	n	i	m	i	z	e
0	1	2	3	4	5	6	7





Tries and Web Search Engines

- Search engine index
  - Collection of all searchable words
  - Stored in compressed trie
- Each leaf of trie
  - Associated with a word
  - List of pages (URLs) containing that word
    - Called occurrence list
- Trie is kept in memory (fast)
- Occurrence lists kept in external memory
  - Ranked by relevance

Computational Biology

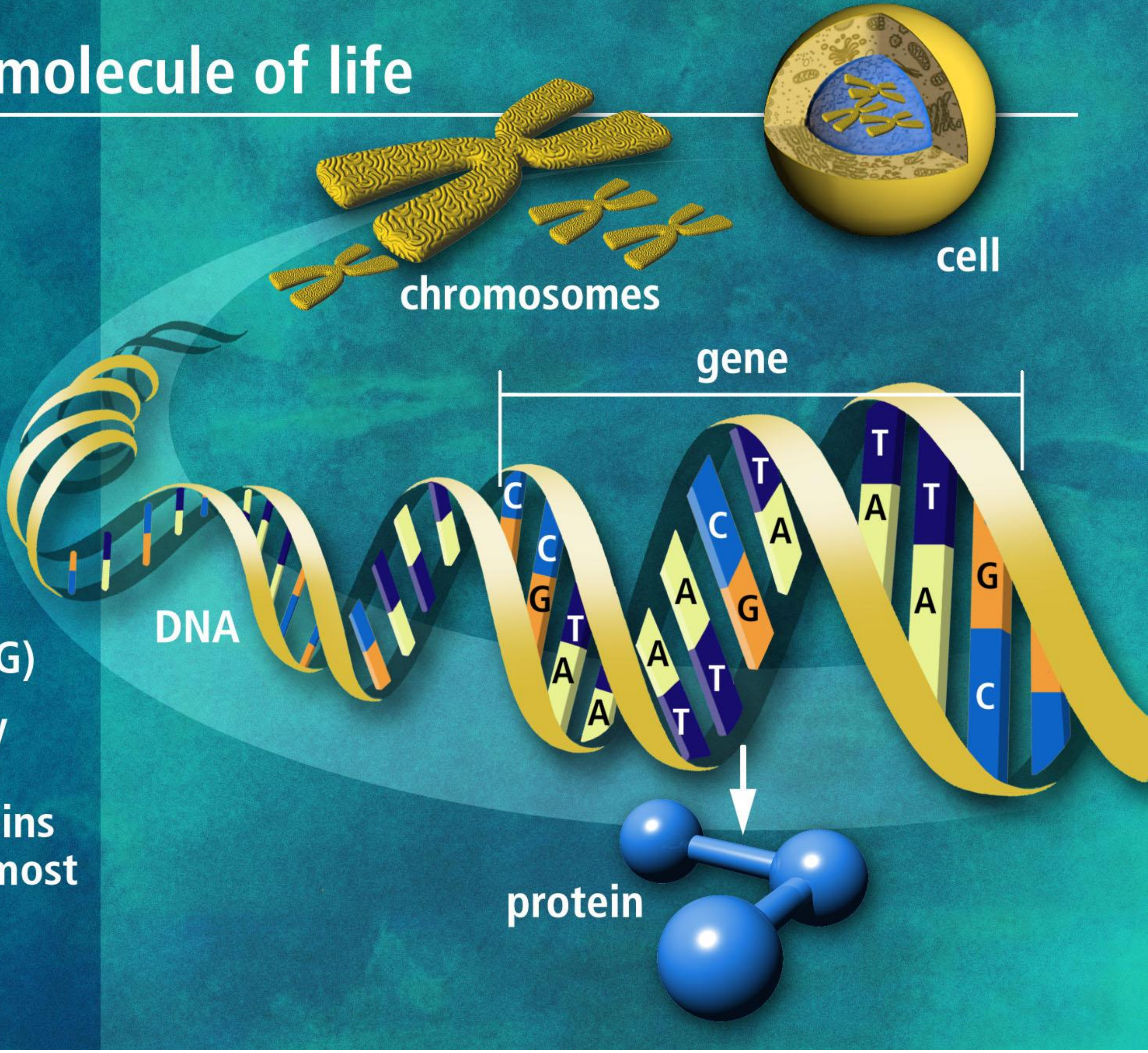
- DNA
  - Sequence of 4 different nucleotides (ATCG)
  - Portions of DNA sequence produce proteins (genes)
- Genome
  - Master DNA sequence for organism
  - For Human
    - 46 chromosomes
    - 3 billion nucleotides

DNA the molecule of life

Trillions of cells

Each cell:

- 46 human chromosomes
- 2 meters of DNA
- 3 billion DNA subunits (the bases: A, T, C, G)
- Approximately 30,000 genes code for proteins that perform most life functions



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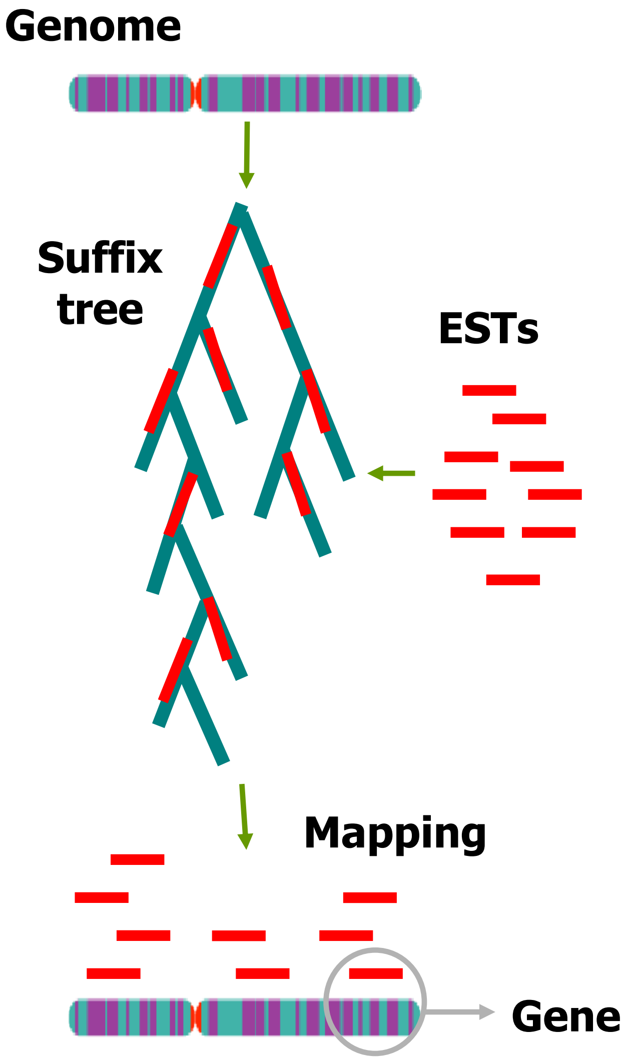
Tries and Computational Biology

- ESTs
  - Fragments of expressed DNA
  - Indicator for genes (& location)
  - 5.5 million sequences at NIH
- ESTmapper
  - Build suffix trie of genome
    - 8 hours, 60 Gbytes
  - Search for ESTs in suffix trie
    - 11 hours w/ 8 processor Sun
- Search genome w/ BLAST
  - 5^+ years (predicted)


Genome
Suffix tree
ESTs
Mapping
Gene