

CS2220 Introduction to Computational Biology  
Lecture 8: Gene Finding by  
Computational Analysis

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## Outline



- Gene structure basics
- Gene finding overview
- GRAIL
- Indel & frame-shift in coding regions

# Gene Structure Basics

## A brief refresher

Some slides here are “borrowed” from Ken Sung



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## Gene



- A gene is a sequence of DNA that encodes a protein or an RNA molecule
- About 30,000 – 35,000 (protein-coding) genes in human genome
- For gene that encodes protein
  - In Prokaryotic genome, one gene corresponds to one protein
  - In Eukaryotic genome, one gene can corresponds to more than one protein because of the process “alternative splicing”

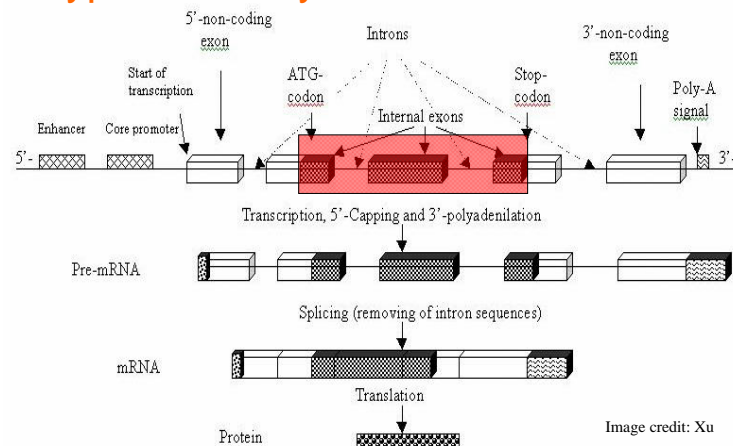
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## Introns and Exons

- **Eukaryotic genes contain introns & exons**
  - Introns are seq that are ultimately spliced out of mRNA
  - Introns normally satisfy GT-AG rule, viz. begin w/ GT & end w/ AG
  - Each gene can have many introns & each intron can have thousands bases
- **Introns can be very long**
- **An extreme example is a gene associated with cystic fibrosis in human:**
  - Length of 24 introns ~1Mb
  - Length of exons ~1kb

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## Typical Eukaryotic Gene Structure





- **Unlike eukaryotic genes, a prokaryotic gene typically consists of only one contiguous coding region**

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## Reading Frame

- Each DNA segment has six possible reading frames

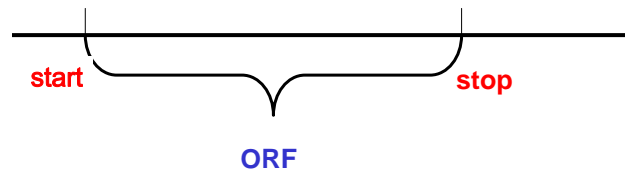
Forward strand:			
	ATGGCTTACGCTTGA		
Reading frame #1	Reading frame #2	Reading frame #3	
ATG	TGG	GGC	
GCT	CTT	TTA	
TAC	ACG	CGC	
GCT	CTT	TTG	
TGC	GA.	A..	
Reverse strand:			
	TCAAGCGTAAGCCAT		
Reading frame #4	Reading frame #5	Reading frame #6	
TCA	CAA	AAG	
AGC	GCG	CGT	
GTA	TAA	AAG	
AGC	GCC	CCA	
CAT	AT.	T..	

How do I get this reverse strand?

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## Open Reading Frame (ORF)

- ORF is a segment of DNA with a start codon and an in-frame stop codon at the two ends and no in-frame stop codon in the middle



- Each ORF has a fixed reading frame

NB: Other definitions are also used. Most imp't aspect is that there is no stop codon in the middle.

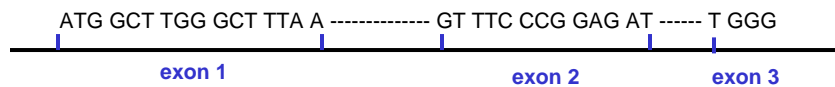
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## Coding Region

- Each coding region (exon or whole gene) has a fixed translation frame
- A coding region always sits inside an ORF of same reading frame
- All exons of a gene are on the same strand
- Neighboring exons of a gene could have different reading frames

## Frame Consistency

- Neighboring exons of a gene should be frame-consistent



Exercise: Define frame consistency mathematically

# Overview of Gene Finding

Some slides here are "borrowed" from Mark Craven



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## What is Gene Finding?

- Find all coding regions from a stretch of DNA sequence, and construct gene structures from the identified exons
- Can be decomposed into
  - Find coding potential of a region in a frame
  - Find boundaries betw coding & non-coding regions

```
atgaacaglacgcatcctctttacaagaaatgggcatctccagtggaattatatcgc  
cccagggtactgcaagggtcagtaggaattagtgtygcagagaaatattcgccttatcact  
gtttccgatgaaaatcagtagctcgcctttgttggtgatgtgctgtaagccttaat  
cttaaaaaagaaaattggttatggttgaattacgatcaaatccagcatatggaatgtaa  
tagcctattcgttattggttactatcagaaaaatagcagccaaattgaccgcactttgcc  
tttgcaagcaggctgagcaggtttatcgctcgccaagttggcagcaatttcaatcfaat  
catcaaaccaaacgacattatgcaaaataaacctcaacacccctaa
```

Image credit: Xu

## Approaches

- **Search-by-signal:** find genes by identifying the sequence signals involved in gene expression
- **Search-by-content:** find genes by statistical properties that distinguish protein coding DNA from non-coding DNA
- **Search-by-homology:** find genes by homology (after translation) to proteins
- **State-of-the-art systems for gene finding usually combine these strategies**

## Relevant Signals for Search-by-Signals

- **Transcription initiation**
  - Promoter
- **Transcription termination**
  - Terminators
- **Translation initiation**
  - Ribosome binding sites
  - Initiation codons
- **Translation termination**
  - Stop codons
- **RNA processing**
  - Splice junction

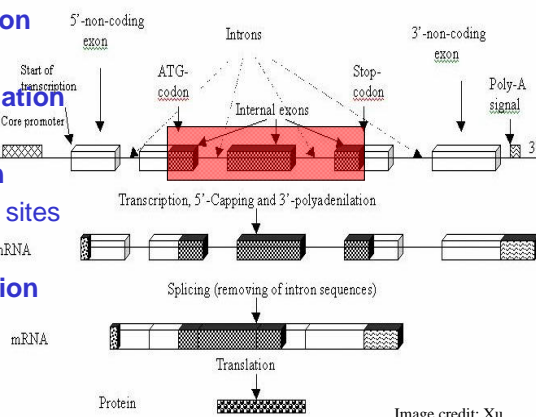



Image credit: Xu

## How Search-by-Signal Works

- There are 2 imp't regions in a promoter seq
  - 10 region, ~10bp before TSS
  - 35 region, ~35bp before TSS
- Consensus for –10 region in *E. coli* is **TATAAT**, but few promoters actually have this seq
- Recognize promoters by
  - weight matrices
  - probabilistic models
  - neural networks, ...

## How Search-by-Content Works

- Encoding a protein affects stats properties of a DNA seq
  - some amino acids used more frequently
  - diff number of codons for diff amino acids
  - for given protein, usually one codon is used more frequently than others
- ⇒ Estimate prob that a given region of seq was “caused by” its being a coding seq



AA	codon	/1000
Gly	GGG	1.89
Gly	GGA	0.44
Gly	GGU	52.99
Gly	GGC	34.55
Glu	GAG	15.68
Glu	GAA	57.20
Asp	GAU	21.63
Asp	GAC	43.26

Image credit: Craven



## How Search-by-Homology Works

- Translate DNA seq in all reading frames
  - Search against protein db
  - High-scoring matches suggest presence of homologous genes in DNA
- ⇒ You can use BLASTX for this

## Search-by-Content Example: Codon Usage Method

- Staden & McLachlan, 1982
- Process a seq w/ “window” of length L
- Assume seq falls into one of 7 categories, viz.
  - Coding in frame 0, frame 1, ..., frame 5
  - Non-coding
- Use Bayes’ rule to determine prob of each category
- Assign seq to category w/ max prob



### Codon Usage Method

$$\Pr(\text{coding}_i | S) = \frac{\Pr(S | \text{coding}_i) \Pr(\text{coding}_i)}{\Pr(S)}$$

probability that sequence encodes a protein in frame i

### Codon Usage Method

- make simplifying assumption that the codons in a window are independent of one another

$$\Pr(S | \text{coding}_i) \approx \prod_{j=1}^n \Pr(S_i(j) | \text{coding}_i)$$

probability of the jth codon in frame i given the sequence is coding

Image credit: Craven



### Codon Usage Method

$$\Pr(\text{coding}_i | S) = \frac{\Pr(S | \text{coding}_i) \Pr(\text{coding}_i)}{\Pr(S)}$$

probability that sequence encodes a protein in frame i

### Codon Usage Method

$$\Pr(S) = \sum_i [\Pr(S | \text{coding}_i) \Pr(\text{coding}_i)] + \frac{\Pr(S | \text{noncoding}) \Pr(\text{noncoding})}{}$$

Sometimes this term is dropped since it's difficult to estimate these statistics

Image credit: Craven



### Codon Usage Method

$$\Pr(\text{coding}_i | S) = \frac{\Pr(S | \text{coding}_i) \Pr(\text{coding}_i)}{\Pr(S)}$$

probability that sequence encodes a protein in frame i

- $\Pr(\text{coding}_i)$  is the same for each frame if window size fits same number of codons in each frame
- Otherwise, consider relative number of codons in window in each frame

Image credit: Craven



### Codon Usage Method

By sliding the window, we can generate predictions for the extent of our sequence

G C T A C G G A G C T T C G G A G C  
 C G A T G C C T C G A A G C C T C G

### Predicted Coding Regions

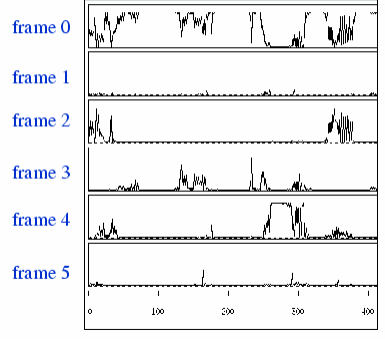
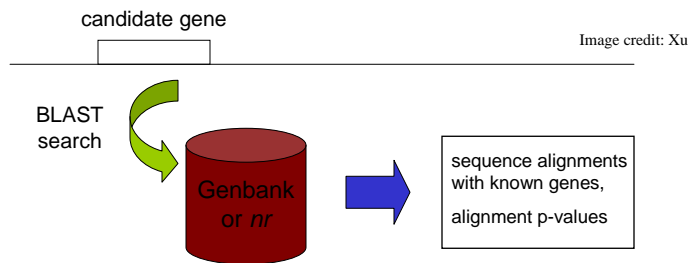


Image credit: Craven

## Search-by-Homology Example: Gene Finding Using BLAST



- High seq similarity typically implies homologous genes
- ⇒ Search for genes in yeast seq using BLAST
- ⇒ Extract Feature for gene identification



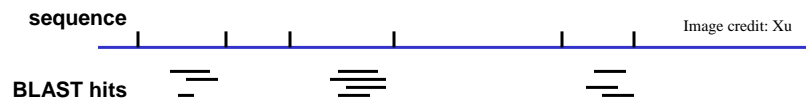
**Search-by-Homology Example:  
Gene Finding Using BLAST**

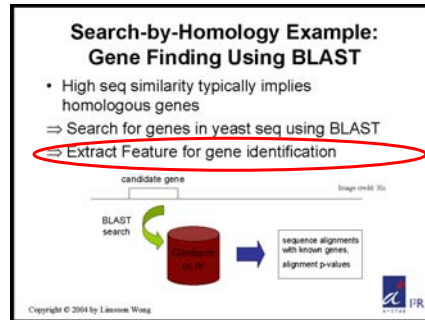
- High seq similarity typically implies homologous genes
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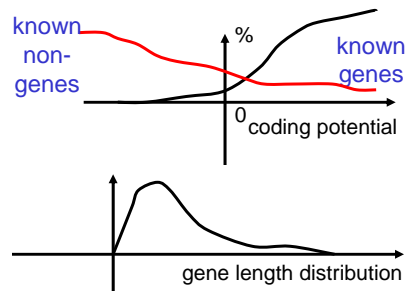


- Searching all ORFs against known genes in nr db helps identify an initial set of (possibly incomplete) genes





- A (yeast) gene starts w/ ATG and ends w/ a stop codon, in same reading frame of ORF
- Have “strong” coding potentials, measured by, preference models, Markov chain model, ...
- Have “strong” translation start signal, measured by weight matrix model, ...
- Have distributions wrt length, G+C composition, ...
- Have special seq signals in flanking regions, ...



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## GRAIL, An Important Gene Finding Program

Signals assoc w/ coding regions

Models for coding regions

Signals assoc w/ boundaries

Models for boundaries

Other factors & information fusion

Some slides here are “borrowed” from Ying Xu



## Coding Signal

- Freq distribution of dimers in protein seq
- E.g., *Shewanella*
  - Ave freq is 5%
  - Some amino acids prefer to be next to each other
  - Some amino acids prefer to be not next to each other

Name	ala	arg	asn	asp	cys	glu	gln	gly	his	ile	leu	lys	met	phe	pro	ser	thr	trp	tyr	val
ala	9.5	4.1	4.3	5.3	1.2	6	4.8	6.5	2	6.5	11.1	6	2.6	3.7	3.5	6.2	5	11.1	2.7	6.5
arg	7.9	5.5	3.9	5.3	1.1	6	5.5	5.9	2.6	6.5	11.4	5	2.2	4.7	3.6	5.5	4.4	1.4	4	6.6
asn	9.6	4.9	4.2	4.9	1	5.3	5.6	7.4	2.3	6	10	4.9	2	3.5	5.1	6.1	5.5	1.5	3.1	6.1
asp	9.3	4	4.7	5.1	1	6.7	2.9	7	1.8	7.1	9.6	6.3	2.3	4.3	3.9	5.9	5.1	1.6	3.6	6.6
cys	8.4	4.8	3.3	5.4	1.7	5.6	5.2	8.1	4.3	5.4	10.2	3.8	1.8	4.1	4.5	6.3	4.3	1.6	3.4	6.8
glu	9.4	5.8	3.6	4.5	0.8	4.9	7	5.8	2.6	5.9	12.7	5	2.4	4	3.5	5.4	5	1.1	2.8	6.8
gln	10.3	4.9	3	4.4	0.9	4.5	6.8	7	2.7	5.5	12.8	4.1	2	3.9	3.8	5.8	5.3	1.4	3	6.9
gly	8.1	4.8	3.9	5.1	1.2	6	4.6	6.4	2.4	6.8	10.5	5.8	2.7	4.8	2.4	5.8	5.1	1.4	3.7	7.5
his	7.3	4.7	4	4.8	1.5	4.9	5.6	6.9	3	6.2	10.8	4.8	1.6	5	5.2	6.8	4.9	1.7	4.2	5.1
ile	11	4.7	4.9	6.5	1.1	6.9	3.6	7.2	2.1	5.3	8.6	5.3	1.8	3.2	4.2	7	5.6	0.9	2.9	6.1
leu	10.4	4.2	4.3	5.2	1.1	5.2	3.7	6.8	2	5.6	10.6	5.3	2.3	3.8	4.5	7.4	6.2	1	2.6	6.6
lys	10.6	5.2	3.8	5.2	0.5	5.3	5.9	6.6	2.6	5.2	11.3	4.7	1.9	2.8	4.6	6	5.5	1.2	2.6	7.6
met	10.8	4.8	3.8	4.6	0.7	4.6	4.9	7	1.7	4.7	11.4	5.2	2.8	3.3	5.1	7.4	6.3	0.9	2	6.8
phe	9.6	3.7	5.2	6.5	1.2	6.4	2.7	7.9	1.9	6.7	7.4	5	2.5	3.9	3.6	8	5.8	1.3	3.3	6.3
pro	8.4	3.6	4.6	5.4	0.7	7.6	5.2	5.4	2.3	6.1	11.2	5.5	2.4	4.2	2.8	6.5	5.4	1.4	2.9	7.5
ser	9.1	4.6	3.7	5	1	5.4	5.2	7.2	2.6	6	11.6	4.5	2.2	4.1	4.1	6.5	5	1.2	3.2	6.8
thr	9.1	4.2	3.7	5.6	0.9	5.7	5.7	7.5	2.2	5.5	12	4.2	2	3.5	5.5	6.2	5.3	1.1	2.6	6.7
trp	7.1	6.3	3.2	4.8	1.3	3.9	8.5	6.6	3.6	5	14.2	3.2	2.4	4.6	3.9	5.8	4.3	1.3	3	6.1
tyr	7.9	6.5	3.6	4.9	1.2	4.5	7	7.1	2.6	5	11.7	4	1.6	4.7	4.9	6.4	4.6	1.5	3.4	5.7
val	9.6	4.1	4.4	5.9	1	6.2	3.4	6.4	1.8	6.5	10.2	5.2	2.5	3.7	3.8	7.2	6.1	1.1	2.7	7.1

Image credit: Xu

Exercise: What is shewanella?

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## Coding Signal

- Dimer preference implies dicodon (6-mers like AAA TTT) bias in coding vs non-coding regions
- Relative freq of a dicodon in coding vs non-coding
  - Freq of dicodon X (e.g, AAA AAA) in coding region = total number of occurrences of X divided by total number of dicodon occurrences
  - Freq of dicodon X (e.g, AAA AAA) in noncoding region = total number of occurrences of X divided by total number of dicodon occurrences

Exercise: In human genome, freq of dicodon “AAA AAA” is ~1% in coding region vs ~5% in non-coding region. If you see a region with many “AAA AAA”, would you guess it is a coding or non-coding region?

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## Why Dicodon (6-mer)?

- Codon (3-mer)-based models are not as info rich as dicodon-based models
- To make stats reliable, need ~15 occurrences of each X-mer
- Tricodon (9-mer)-based models need too many data points
- ⇒ For tricodon-based models, need at least  $15 \times 262144 = 3932160$  coding bases in our training data, which is probably not going to be available for most genomes

There are

$4^3 = 64$  codons

$4^6 = 4096$  dicodons

$4^9 = 262144$  tricodons

## Coding Signal

- Most dicodons show bias toward either coding or non-coding regions
- ⇒ Foundation for coding region identification
- Regions consisting of dicodons that mostly tend to be in coding regions are probably coding regions; otherwise non-coding regions
- ⇒ Dicodon freq are key signal used for coding region detection; all gene finding programs use this info



## Coding Signal

- Dicodon freq in coding vs non-coding are genome-dependent

Image credit: Xu

Name	ala	arg	asn	asp	cys	gln	gly	his	ile	leu	lys	met	phe	pro	ser	thr	trp	tyr	val	
ala	95	41	43	53	12	6	48	65	2	65	115	6	26	37	35	62	5	11	27	65
arg	79	55	39	59	111	6	55	59	26	65	114	5	22	47	36	55	44	14	4	66
asn	96	49	42	49	1	53	56	74	23	6	10	49	2	35	51	61	55	15	31	61
asp	93	4	47	51	1	67	29	7	18	71	96	63	23	43	39	59	51	16	36	66
cys	84	48	33	54	17	56	52	81	43	54	102	38	18	41	45	63	43	16	34	68
gln	94	58	36	45	08	49	7	58	26	59	127	5	24	4	35	54	5	11	28	68
gly	103	49	3	44	09	45	68	7	27	55	128	41	7	39	38	58	53	14	3	69
his	81	48	39	51	112	6	46	64	24	68	105	58	27	48	24	58	51	14	37	75
ile	73	47	4	48	15	49	56	69	3	62	108	48	16	5	52	68	49	17	42	51
leu	11	47	49	65	11	69	36	72	21	53	86	53	18	32	42	7	56	09	29	61
lys	104	42	43	52	11	52	37	68	2	56	106	53	23	38	45	74	62	1	26	66
met	106	52	38	52	05	53	59	66	26	52	113	47	19	28	46	6	55	12	26	76
phe	108	48	38	46	07	46	49	7	17	47	114	52	28	33	51	74	63	09	2	68
pro	96	37	52	65	12	64	27	79	19	67	74	5	25	39	36	8	58	13	33	63
ser	84	36	46	54	07	76	52	54	23	61	112	55	24	42	28	65	54	14	29	75
thr	91	46	37	5	1	54	52	72	26	6	116	45	22	41	41	65	5	12	32	68
trp	91	42	37	56	09	57	75	22	55	12	42	2	35	55	62	53	11	26	67	
tyr	71	63	32	48	13	39	85	66	36	5	142	32	24	46	39	58	43	13	3	61
val	79	65	36	49	12	45	7	71	26	5	117	4	16	47	49	64	46	15	34	57
val	96	41	44	59	1	62	34	64	18	65	102	52	25	37	38	72	61	11	27	71

Shewanella

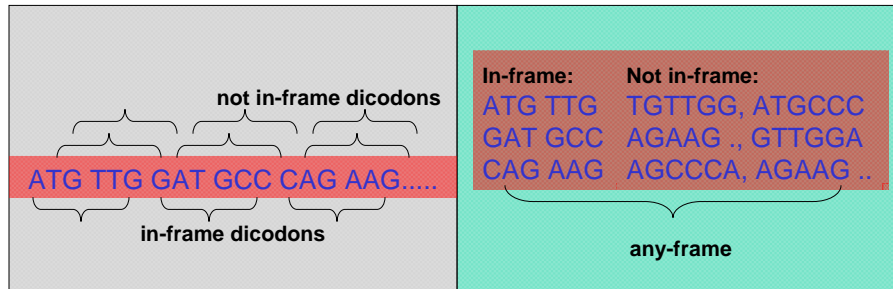
Bovine

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## Coding Signal

- In-frame vs any-frame dicodons
- In-frame dicodon freq provide a more sensitive measure than any-frame dicodon freq



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## Dicodon Preference Model

- The preference value  $P(X)$  of a dicodon  $X$  is defined as

$$P(X) = \log FC(X)/FN(X)$$

where

$FC(X)$  is freq of  $X$  in coding regions

$FN(X)$  is freq of  $X$  in non-coding regions



## Dicodon Preference Model's Properties

- $P(X) = 0$  if  $X$  has same freq in coding and non-coding regions
- $P(X) > 0$  if  $X$  has higher freq in coding than in non-coding region; the larger the diff, the more positive the score is
- $P(X) < 0$  if  $X$  has higher freq in non-coding than in coding region; the larger the diff, the more negative the score is

## Dicodon Preference Model Example

- Suppose AAA ATT, AAA GAC, AAA TAG have the following freq:

$$FC(\text{AAA ATT}) = 1.4\%$$

$$FN(\text{AAA ATT}) = 5.2\%$$

$$FC(\text{AAA GAC}) = 1.9\%$$

$$FN(\text{AAA GAC}) = 4.8\%$$

$$FC(\text{AAA TAG}) = 0.0\%$$

$$FN(\text{AAA TAG}) = 6.3\%$$

- Then

$$P(\text{AAA ATT}) = -0.57$$

$$P(\text{AAA GAC}) = -0.40$$

$$P(\text{AAA TAG}) = -\infty,$$

treating STOP codons differently

- ⇒ A region consisting of only these dicodons is probably a non-coding region

## Frame-Insensitive Coding Region Preference Model

- A frame-insensitive coding preference  $S_{is}(R)$  of a region  $R$  can be defined as

$$S_{is}(R) = \sum_{X \text{ is a dicodon in } R} P(X)$$

- $R$  is predicted as coding region if  $S_{is}(R) > 0$

NB. This model is not commonly used



## In-Frame Dicodon Preference Model

- The in-frame + i preference value  $P_i(X)$  of a dicodon X is defined as

$$P_i(X) = \log FC_i(X)/FN(X)$$

where

$FC_i(X)$  is freq of X in coding regions  
at in-frame + i positions

$FN(X)$  is freq of X in non-coding regions



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## In-Frame Coding Region Preference Model

- The in-frame + i preference  $S_i(R)$  of a region R can be defined as

$$S_i(R) = \sum_{X \text{ is a dicodon at in-frame + i position in } R} P_i(X)$$

- R is predicted as coding if  $\sum_{i=0,1,2} S_i(R)/|R| > 0$

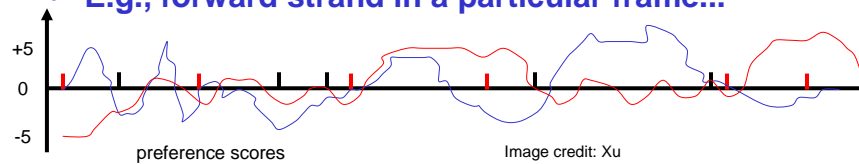
**NB.** This coding preference model is commonly used

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## Coding Region Prediction: An Example Procedure



- Calculate all ORFs of a DNA segment
- For each ORF
  - Slide thru ORF w/ increment of 10bp
  - Calculate in-frame coding region preference score, in same frame as ORF, within window of 60bp
  - Assign score to center of window
- E.g., forward strand in a particular frame...

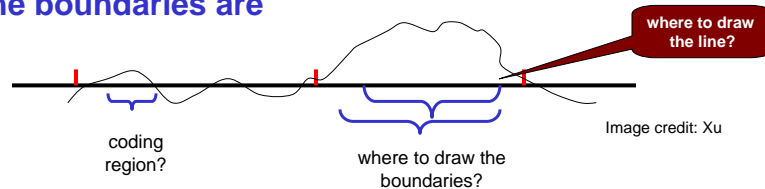


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## Problem with Coding Region Boundaries



- Making the call: coding or non-coding and where the boundaries are



- ⇒ Need training set with known coding and non-coding regions to select threshold that includes as many known coding regions as possible, and at the same time excludes as many known non-coding regions as possible

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## Types of Coding Region Boundaries

- Knowing boundaries of coding regions helps identify them more accurately
- Possible boundaries of an exon



- **Splice junctions:**
  - Donor site: coding region | GT
  - Acceptor site: CAG | TAG | coding region
- **Translation start**
  - in-frame ATG

What do you expect at translation stop?

## Signals for Coding Region Boundaries

- Splice junction sites and translation starts have certain distribution profiles
- For example, ...

## Acceptor Site (Human Genome)

- If we align all known acceptor sites (with their splice junction site aligned), we have the following nucleotide distribution

	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1
A	11.1	12.7	3.2	4.8	12.7	8.7	16.7	16.7	12.7	9.5	26.2	6.3	100	0.0	21.4
C	36.5	30.9	19.1	23.0	34.9	39.7	34.9	40.5	40.5	36.5	33.3	68.2	0.0	0.0	7.9
G	9.5	10.3	15.1	12.7	8.7	9.5	16.7	4.8	2.4	6.3	13.5	0.0	0.0	100	62.7
U	38.9	41.3	58.7	55.6	42.1	40.5	30.9	37.3	44.4	47.6	27.0	25.4	0.0	0.0	7.9

Image credit: Xu

- Acceptor site: CAG | TAG | coding region

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## Donor Site (Human Genome)

- If we align all known donor sites (with their splice junction site aligned), we have the following nucleotide distribution

	-3	-2	-1	1	2	3	4	5	6
A	34.0	60.4	9.2	0.0	0.0	52.6	71.3	7.1	16.0
C	36.3	12.9	3.3	0.0	0.0	2.8	7.6	5.5	16.5
G	18.3	12.5	80.3	100	0.0	41.9	11.8	81.4	20.9
U	11.4	14.2	7.3	0.0	100	2.5	9.3	5.9	46.2

Image credit: Xu

- Donor site: coding region | GT

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## What Positions Have “High” Info Content?

- For a weight matrix, information content of each column is calculated as

$$-\sum_{X \in \{A,C,G,T\}} F(X) \log(F(X)/0.25)$$

- When a column has evenly distributed nucleotides, its information content is lowest
- Only need to look at positions having high information content

## Information Content Around Donor Sites in Human Genome

	-3	-2	-1	1	2	3	4	5	6
A	34.0	60.4	9.2	0.0	0.0	52.6	71.3	7.1	16.0
C	36.3	12.9	3.3	0.0	0.0	2.8	7.6	5.5	16.5
G	18.3	12.5	80.3	100	0.0	41.9	11.8	81.4	20.9
U	11.4	14.2	7.3	0.0	100	2.5	9.3	5.9	46.2

Image credit: Xu

- Information content**

$$\begin{aligned} \square \text{column } -3 &= - .34 \log (.34/.25) - .363 \log (.363/.25) - .183 \log (.183/.25) - .114 \log (.114/.25) \\ &= 0.04 \end{aligned}$$

$$\begin{aligned} \square \text{column } -1 &= - .092 \log (.92/.25) - .03 \log (.033/.25) - .803 \log (.803/.25) - .073 \log (.73/.25) \\ &= 0.30 \end{aligned}$$

## Weight Matrix Model for Splice Sites



- **Weight matrix model**
  - Build a weight matrix for donor, acceptor, translation start site, respectively
  - Use positions of high information content

	-3	-2	-1	1	2	3	4	5	6
<b>A</b>	34.0	60.4	9.2	0.0	0.0	52.6	71.3	7.1	16.0
<b>C</b>	36.3	12.9	3.3	0.0	0.0	2.8	7.6	5.5	16.5
<b>G</b>	18.3	12.5	80.3	100	0.0	41.9	11.8	81.4	20.9
<b>U</b>	11.4	14.2	7.3	0.0	100	2.5	9.3	5.9	46.2

Nucleotide distribution around human donor sites

Image credit: Xu

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## Just to make sure you know what I mean ...



- **Give me 3 DNA seq of length 10:**
  - Seq<sub>1</sub> = ACCGAGTTCT
  - Seq<sub>2</sub> = AGTGTACCTG
  - Seq<sub>3</sub> = AGTTCGTATG
- **Then the weight matrix is ...**

1-mer	pos1	pos2	pos3	pos4	pos5	pos6	pos7	pos8	pos9	pos10
<b>A</b>	3/3	0/3	0/3							
<b>C</b>	0/3	1/3	1/3							
<b>G</b>	0/3	2/3	0/3							
<b>T</b>	0/3	0/3	2/3							

Exercise: Fill in the rest of the table

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## Splice Site Prediction: A Procedure

	-3	-2	-1	1	2	3	4	5	6
<b>A</b>	34.0	60.4	9.2	0.0	0.0	52.6	71.3	7.1	16.0
<b>C</b>	36.3	12.9	3.3	0.0	0.0	2.8	7.6	5.5	16.5
<b>G</b>	18.3	12.5	80.3	100	0.0	41.9	11.8	81.4	20.9
<b>U</b>	11.4	14.2	7.3	0.0	100	2.5	9.3	5.9	46.2

Nucleotide distribution around human donor sites

Image credit: Xu

- **Add up freq of corr letter in corr positions:**

**AAGGTAAGT**:  $.34 + .60 + .80 + 1.0 + 1.0$   
 $+ .52 + .71 + .81 + .46 = 6.24$

**TGTGTCTCA**:  $.11 + .12 + .03 + 1.0 + 1.0$   
 $+ .02 + .07 + .05 + .16 = 2.56$

- **Make prediction on splice site based on some threshold**

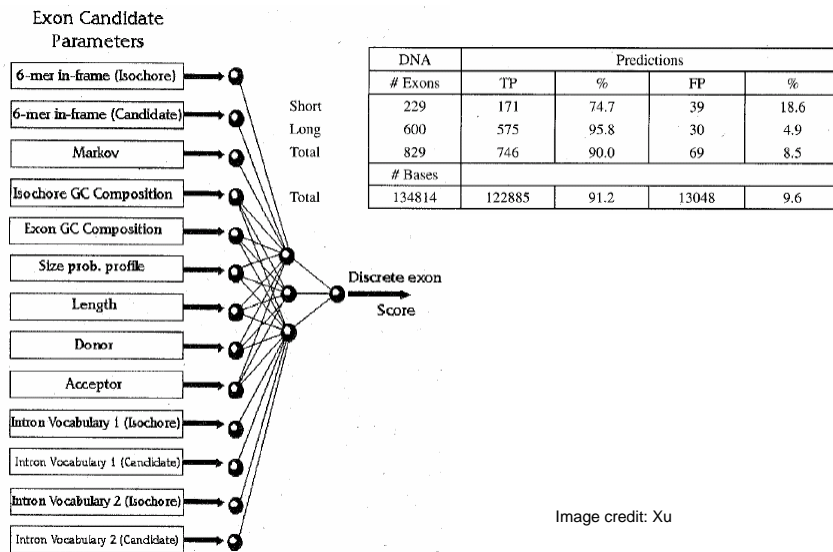
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## Other Factors Considered by GRAIL

- **G+C composition affects dicodon distributions**
- **Length of exons follows certain distribution**
- **Other signals associated with coding regions**
  - periodicity
  - structure information
  - .....
- **Pseudo genes**
- .....

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## Info Fusion by ANN in GRAIL



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## Remaining Challenges in GRAIL

- Initial exon
- Final exon
- Indels & frame shifts

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# Indel & Frame-Shift in Coding Regions

- Problem definition
- Indel & frameshift identification
- Indel correction
- An iterative strategy

Some slides here are "borrowed" from Ying Xu



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## Indels in Coding Regions



- Indel = insertion or deletion in coding region
- Indels are usually caused by seq errors

ATG GAT CCA CAT ..... → ATG GAT CA CAT .....  
ATG GAT CTCA CAT .....

## Effects of Indels on Exon Prediction

- Indels may cause shifts in reading frames & affect prediction algos for coding regions

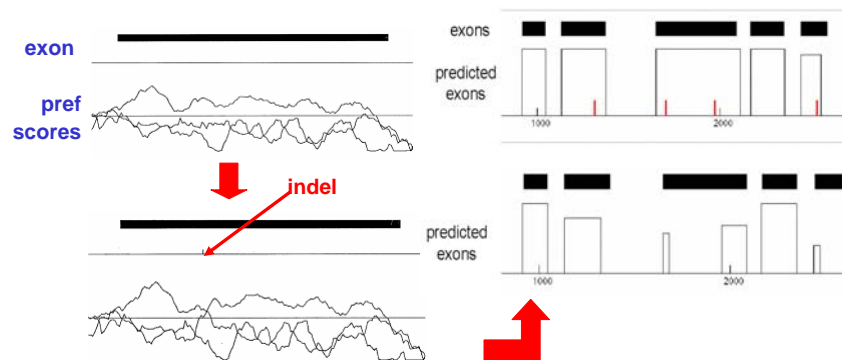


Image credit: Xu

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## Key Idea for Detecting Frame-Shift

- Preferred reading frame is reading frame w/ highest coding score
- Diff DNA segments may have diff preferred reading frames

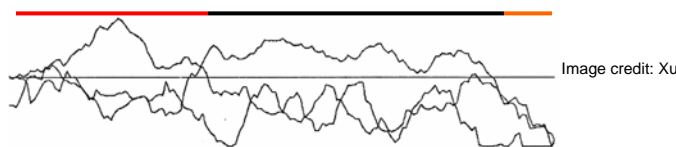


Image credit: Xu

- ⇒ Segment a coding sequence into regions w/ consistent preferred reading frames corr well w/ indel positions
- ⇒ Indel identification problem can be solved as a sequence segmentation problem!

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## Frame-Shift Detection by Seq Segmentation

- **Partition seq into segs so that**
  - Chosen frames of adjacent segs are diff
  - Each segment has >30 bps to avoid small fluctuations
  - Sum of coding scores in the chosen frames over all segments is maximized

## Frame-Shift Detection: A Simplified Treatment

- Given DNA sequence  $a_1 \dots a_n$
- Define key quantities

$$C(i, r) = \text{max score on } a_1 \dots a_i \\ \text{w/ the last segment in frame } r$$

- Then

$$\max_{r \in \{0, 1, 2\}} C(n, r) \text{ is optimal solution}$$

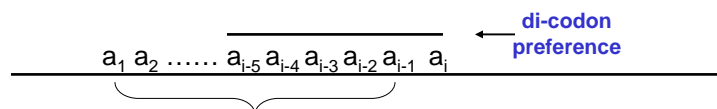
## Frame-Shift Detection: $C(i,r)$

- To calculate  $C(i,r)$ , there are 3 possible cases for each position  $i$ :
    - Case 1: no indel occurred at position  $i$
    - Case 2:  $a_i$  is an inserted base
    - Case 3: a base has been deleted in front of  $a_i$
- ⇒  $C(i, r) = \max \{ \text{Case 1, Case 2, Case 3} \}$

## Frame-Shift Detection: Case 1

- No indel occurs at position  $i$ . Then

$$C(i,r) = C(i-1, r') + P_r(a_{i-5} \dots a_i)$$

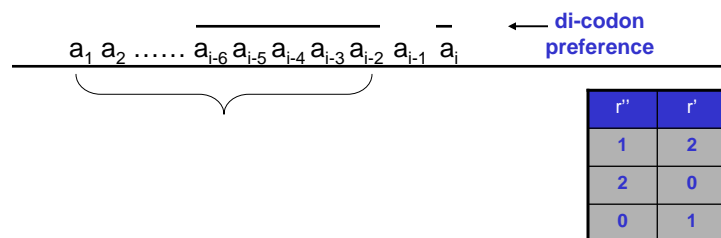


$r''$	$r'$	$r$
1	2	0
2	0	1
0	1	2

## Frame-Shift Detection: Case 2

- $a_{i-1}$  is an inserted base. Then

$$C(i, r) = C(i-2, r') + P_r(a_{i-6} \dots a_{i-2} a_i)$$

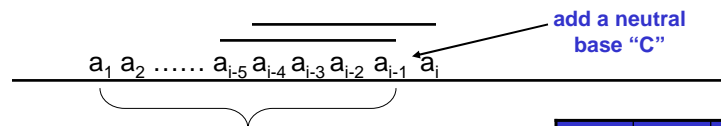


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## Frame-Shift Detection: Case 3

- A base has been deleted in front of  $a_i$ . Then

$$C(i, r) = C(i-1, r'') + P_{r'}(a_{i-5} \dots a_{i-1} C) + P_r(a_{i-4} \dots a_{i-1} C a_i)$$



Exercise: why is "C" is best choice for the purpose above?

$r''$	$r'$	$r$
1	2	0
2	0	1
0	1	2

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## Frame-Shift Detection: Initiation



- Initial conditions,
 
$$C(k, r) = -\infty, k < 6$$

$$C(6, r) = P_r(a_1 \dots a_6)$$
- This is a dynamic programming (DP) algorithm; the equations are DP recurrences

Exercise: How to modified the recurrence so that each fragment is at least 30bp?

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## Frame-Shift Detection: Determining Indel Positions



- Calculation of  $\max_{r \in \{0, 1, 2\}} C(i, r)$  gives an optimal segmentation of a DNA sequence
- Tracing back the transition points---viz. case 2 & case 3---gives the segmentation results

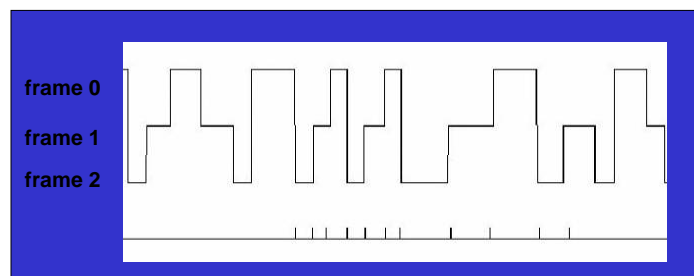


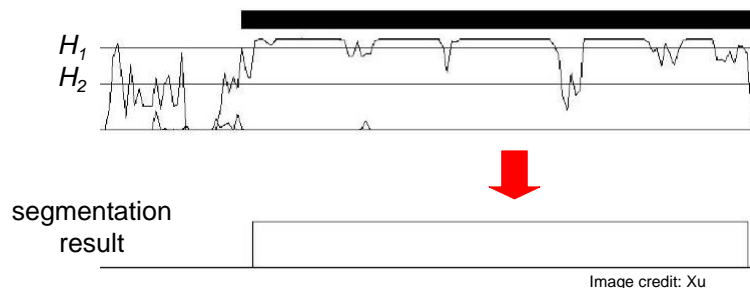
Image credit: Xu

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## Frame-Shift Detection: Determine Coding Regions

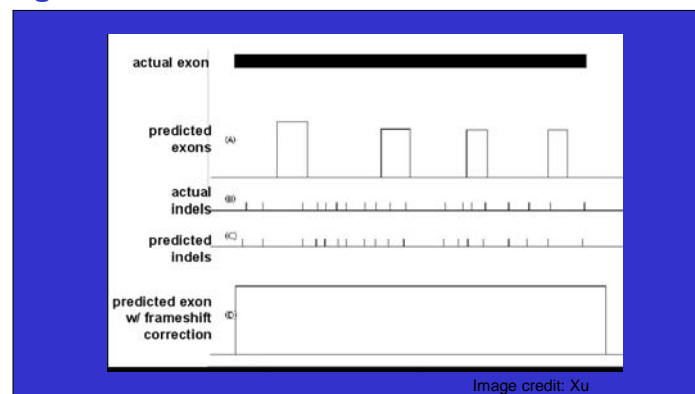
- For given  $H_1$  and  $H_2$  (e.g., = 0.25 for noncoding and 0.75 for coding), partition a DNA seq into segs so that each seg has  $>30$  bases & coding values of each seg are consistently closer to one of  $H_1$  or  $H_2$  than the other



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## Frame-Shift Detection: Finally...

- Overlay “preferred reading-frame segs” & “coding segs” gives coding region predictions regions w/ indels

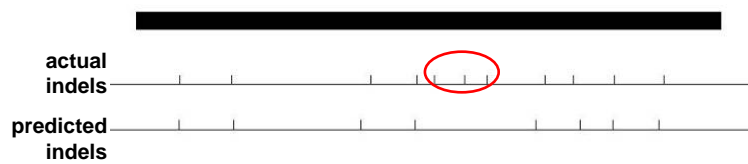


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## What Happens When Indels Are Close Together?



- Our procedure works well when indels are not too close together (i.e., >30 bases apart)
- When indels are too close together, they will be missed...



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## Handling Indels That Are Close Together



- **Employ an iterative process, viz**
  - Find one set of indels
  - Correct them
  - Iterate until no more indels can be found



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Any Question?



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## Acknowledgements



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