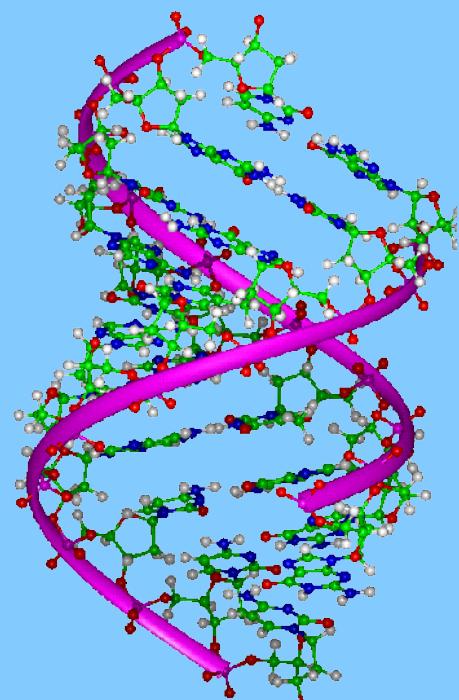


Basic Bioinformatics

A Practical User Introduction

Sunday 6 March 2016



This material is intended to be used for self instruction or in a more formal class setting. When offered as a set of class exercises, I describe my intentions as follows:

Overview

This is an **entry level** course aimed at those with a reasonable biological background but **no significant experience with bioinformatics**. The course is broadly based around a series of exercises in which a combination of simple analytical tools and publicly available databases is applied to the investigation of a single human gene. The training manual for the course is comprised of detailed instruction for the tasks undertaken. Included are, questions (with answers) and discussion of and the interpretation of the results achieved. The manual is under constant development, a recent version is available online.

Outline

Participants are asked to imagine an interest in the disease **aniridia**. Course exercises then provide extremely detailed instruction leading participants to discover the gene primarily associated with this disease and all that is interesting about that gene and its protein products.

Objectives

This course is not intended to fully meet the requirements of many modern research projects. The intention is more to examine and practice the basic tools that underpin many current bioinformatic solutions and have changed little over the years. Specifically, we set out to show how many answers can be simply be looked up in an appropriate information source and/or how it is also usually a trivial matter to compute the similar/identical answers using readily available software.

We set out to explain the operation of the various programs used in the exercise, but only to the extent that allows a user to select parameters intelligently and to interpret results fully.

Timetable

The main topics covered, in order, are as follows:

Simple Information and Data (i.e. sequence) retrieval from public resources (primarily the **NCBI** and **EBI**).

Genome Databases (primarily **Ensembl** including access using **Biomart**)

Pairwise Sequence Alignment (**dotplots**, **global** and **local** alignments)

Database searching (using elements of the **blast** family)

Primer design (primarily using the **NCBI** services)

Secondary Structure Prediction (**GOR**, **JPred**)

Multiple Sequence Alignment (**clustal**, **muscle**, **t-coffee** ...)

PSI-blast (an explicit example, but incorporated into a number of the previous topics)

3D Structure (a very superficial look specific to the exercise protein)

The timing can vary depending on circumstances. A very rushed **3 days** to a relatively leisurely **5 days**.

DPJ – 2016.03.03

Course Objectives

The aim is to present a hands-on introduction to the ways computer resources can be utilised to assist the molecular biological researcher. Our target audience is the informed biologist who is new to using the computer for such a purpose. We cannot cover “everything” but hope to introduce a range of computing facilities available to answer simple molecular biological enquiries. Where appropriate, how programs work will be discussed, but only as far as is required to understand the parameters that a user is required to set and the results generated. We will assume that a brief introductory talk mentioning the more important databases has been delivered before offering these exercises.

There will be a mixture of talks and frequent practical sessions. During the practical sessions you are encouraged to go through the exercises in the book, as far as is practical, at your own pace. Please ask for assistance at any time you are unsure how to proceed or require clarification on any point.

At various points in the exercises, you will be asked to answer simple questions. The purpose of the questions is to draw your attention to some aspect of what you are doing rather than to test your understanding. Sometimes, the answers you note down will be useful later in the exercise, so try not to skip over the questions. If you cannot answer any question, please just ask¹.

It is now less usual than previously for individual researchers to meticulously analyse small volumes of data. Sequence data is typically generated and analysed by large, well equipped, Institutes. Whole genomes are processed in a single project. Sequence data, analytical results and associated, often automated, interpretation are centrally organised for easy access. In consequence, many investigations can be completed by simply locating answers stored in information rich databases. Accordingly, our exercises will be roughly split into two sections. In the first we will take a topic and see how it is possible to discover effectively all one would wish to know from various combinations of appropriate information resources over the internet. In the second section we will look at how many of the same conclusions might have been reached by applying analytical software to raw sequence data. The software tools we will use are essentially those used to generate the pre-processed “answers” achieved in the first section so it should not be surprising that the results will be very similar.

Of course, we will cheat! Our topic will be a well researched one to ensure that there is a full set of pre-processed answers to find in the databases we interrogate. But the principles we will use are universal. As completely as we were able, we have built all the exercises around a single starting point. That is, a need to find out all there is to know about the human disease of the eye called **aniridia**.

If your research does not involve humans, please do not be concerned. Using a human example ensures a well researched topic, but very few of the resources we will visit are specifically human. The basic principles of how to proceed really are not organism specific.

DPJ/PDFJ – 2016.03.03

¹ If you are working from the **PDF** version of these notes, some “model answers” can be accessed via the link that is behind the [?](#) or [.](#) that terminates each question. This is “work in progress”, I am far from completion at the time of typing.

Searching for ready made answers

To recap, our objective is to discover what we can about the disease **aniridia** and its causes. There are many ways we could begin, including the ultimately lazy (but often very effective) universal strategy of “google”. In an attempt to be slightly more directed, and as our example query involves a human disease, we will start with **GeneCards**.

GeneCards

If we assume the disease might be genetically linked, a sensible starting service for our investigations might be **GeneCards**, a famous service maintained in Israel by the **Weizmann Institute**. **Genecards** is:

“ ... a searchable, integrated, database of human genes that provides concise genomic, transcriptomic, genetic, proteomic, functional and disease related information on all known and predicted human genes”

Information from many sources is stored for each human² gene in a “card”. These cards can be searched using clues (**Keywords**) specifying your interests to determine the gene(s) that might be of interest. In addition to summarising what is known about a gene, each **GeneCard** offers links to pertinent internet resources for further investigation. Effectively, **GeneCards** has searched tens of databases for each gene and saved the results as links. Thus, one search of **GeneCards** can substitute for many individual searches of other resource sites.

Hopefully you have a browser window open at this stage, if not, open one up and go to:

<http://www.genecards.org>

Leave the type of search set to set to **Keywords**, enter the **Search Term aniridia** and click the  button. You will be rewarded with a list of links to **GeneCards** in order of “relevance”³.

	Symbol	Description	Category	GIFs	GC Id	Score ▼
1	 PAX6	Paired Box 6	Protein Coding	61	GC11M031806	59.98
2	 WT1	Wilms Tumor 1	Protein Coding	66	GC11M032365	18.21
3	 ELP4	Elongator Acetyltransferase Complex Subunit 4	Protein Coding	49	GC11P031487	15.40
4	 DEL11P13	Wilms Tumor, Aniridia , Genitourinary Anomalies And Mental Retardation Syndrome	Uncategorized	4	GC11U901781	14.72
5	 LUZP2	Leucine Zipper Protein 2	Protein Coding	47	GC11P024518	14.67
6	 FOXC1	Forkhead Box C1	Protein Coding	56	GC06P001610	14.46
7	 PITX2	Paired-Like Homeodomain 2	Protein Coding	57	GC04M110617	13.01
8	 FOXE3	Forkhead Box E3	Protein Coding	43	GC01P047416	13.01
9	 CYP1B1	Cytochrome P450, Family 1, Subfamily B, Polypeptide 1	Protein Coding	63	GC02M038034	12.94
10	 LGR4	Leucine-Rich Repeat Containing G Protein-Coupled Receptor 4	Protein Coding	52	GC11M027345	12.91
11	 KRT12	Keratin 12, Type I	Protein Coding	49	GC17M040861	12.33
12	 OTX2	Orthodenticle Homeobox 2	Protein Coding	58	GC14M056799	12.33
13	 PAX4	Paired Box 4	Protein Coding	55	GC07M127610	12.33
14	 IGF2	Insulin-Like Growth Factor 2	Protein Coding	63	GC11M002130	11.80

The score for each **GeneCard** suggests how close a match has been found between your search term(s) and the gene. The top hit should be a clear “winner”.

Words matching search terms are marked in red.

What do you conclude to be the gene most relevant to **aniridia**? _____

2 There is also a **mouse genecards**. Maybe more to follow?

3 A computer's idea of “relevance” may not match yours. Here, the **Score** used to rank hits takes account of the frequency of the search term(s) weighted by where terms occur (e.g. in a “**Title**” would imply more importance than in a “**Comment**” field, perhaps?) and the specificity of the term (e.g. “the” is not specific, “**aniridia**” is). Only if you are really fascinated by this sort of thing try:

<https://www.elastic.co/guide/en/elasticsearch/guide/current/scoring-theory.html>

To confirm the top hit as the best match, click a few of the

1		PAX6	Paired Box 6	Protein Coding	61	GC11M031806	59.98
Aliases (3/4)							
<ul style="list-style-type: none"> > Alias: paired box gene 6 (aniridia, keratitis) > Alias: aniridia type II protein > Alias: aniridia 							
Disorders							
<ul style="list-style-type: none"> > Aniridia (AN) [MIM:106210]: A congenital, bilateral, panocular absence of the iris or extreme iris hypoplasia. Aniridia is not just an isolated defect in iris development... > Aniridia, cerebellar ataxia and mental deficiency (ACAMD) ... > Isolated Aniridia > Aniridia 							
<i>from MalaCards - The human disease database (15/105)</i>							
Summaries for diseases linked to the gene PAX6 (5/35)							
<ul style="list-style-type: none"> > Aniridia: aniridia is an eye disorder characterized by a complete or... may cause the pupils to be abnormal or misshapen. aniridia can cause reduction in the sharpness of vision (v... and increased sensitivity to light (photophobia). aniridia may occur either as an isolated eye abnormality or as part of the wilm's tumor-aniridia-genital anomalies-retardation (wAGR) syndrome. people with aniridia can also have other eye problems including increases to the brain (optic nerves). individuals with aniridia may also have involuntary eye movements (nystagmus)...cally the same in both eyes. rarely, people with aniridia have behavioral problems, developmental delay, and... national library of medicine. aniridia. genetics home reference. june 2009; http://ghr.nlm.nih.gov/condition/aniridia. accessed 3/30/2011. hingorani, i.m., moore a. aniridia. genereviews. august 12, 2008; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2508333/ > Aniridia: Aniridia is the absence of the iris, usually involving both genital or caused by a penetrant injury. Isolated aniridia is a congenital disorder which is not limited to... nystagmus, amblyopia, buphthalmos, and cataract. Aniridia in some individuals is associated with kidney neph... Aniridia > Gillespie Syndrome: Gillespie syndrome, also called aniridia, cerebellar ataxia and mental deficiency and Gill... disorder. The disorder is characterized by partial aniridia (meaning that part of the iris is missing), ataxia... Aniridia > Aniridia: Aniridia is an eye disorder characterized by a complete or... may cause the pupils to be abnormal or misshapen. Aniridia can cause reduction in the sharpness of vision (v... Aniridia > Aniridia: Although called aniridia, this disorder is a panocular one taking its name... See also Gillespie syndrome (206700), in which aniridia is associated with cerebellar ataxia and mental r... Aniridia 							
Symptoms for diseases linked to the gene PAX6 (5/35)							
<ul style="list-style-type: none"> > Isolated Aniridia: aniridia/iris hypoplasia Aniridia > Gillespie Syndrome: aniridia/iris hypoplasia Aniridia > Gillespie Syndrome: aniridia Aniridia > WAGR Syndrome: aniridia/iris hypoplasia Aniridia > Wilms Tumor Susceptibility-5: aniridia/iris hypoplasia Aniridia 							
Aliases for diseases linked to the gene PAX6 (5/35)							
<ul style="list-style-type: none"> > Isolated Aniridia: isolated aniridia > Gillespie Syndrome: aniridia, cerebellar ataxia and mental deficiency Aniridia > Gillespie Syndrome: aniridia, cerebellar ataxia, and mental retardation Aniridia > Gillespie Syndrome: aniridia-cerebellar ataxia-intellectual disability Aniridia > Gillespie Syndrome: aniridia-cerebellar ataxia-mental deficiency Aniridia 							
Publications (5/105)							
<ul style="list-style-type: none"> > Comparison between aniridia with and without PAX6 mutations: clinical and molecular analysis in 14 Korean patients with aniridia. Aniridia > Paired box mutations in familial and sporadic aniridia predicts truncated aniridia proteins. Aniridia > PAX6 mutations in aniridia. Aniridia > Mutation in the PAX6 gene in twenty patients with aniridia. Aniridia > PAX6 mutation as a genetic factor common to aniridia and glucose intolerance. Aniridia 							
Summaries							
<ul style="list-style-type: none"> > EntrezGene: This gene encodes a homeobox and paired domain-containing regions can cause ocular disorders such as aniridia and Peter's anomaly. Use of alternate promoters a... 							
Variants (1/28)							
<ul style="list-style-type: none"> > Aniridia (AN) 							

Follow the link to the most relevant **GeneCard**.

At the top of the **GeneCard** is a table offering the opportunity to **Jump to** any of the **sections** of the **GeneCard** easily.

Jump to section	Aliases	Disorders	Domains	Drugs	Expression	Function	Genomics	Localization	Orthologs
	Paralogs	Pathways	Products	Proteins	Publications	Sources	Summaries	Transcripts	Variants

Discover some of the properties of **PAX6** using the **Jump to section** menu.

Cytogenetic location (**Jump to the Genomics section**).

Number of UniProt isoforms (**Jump to the Proteins section**).

Jump to the Transcripts section. Notice the number of estimated **PAX6** transcripts is inconsistent. In particular:

How many transcripts are predicted by matches to mRNAs in **REFSEQ**?

How many transcripts are predicted by the Alternative Splicing Database (**ASD**)?

How many transcripts are predicted by **Ensembl**?

How would you rationalize the discrepancies?

Within the **Transcripts** section, there is an **Additional mRNA sequences**: subsection listing mRNA sequences from **Genbank**⁵ that match **PAX6**. Follow the link to the **Genbank** entry with accession code **BX640762.1**⁶. You will be taken to the entry as it is stored in the **Genbank** database. The sequence and its annotation is displayed in **Genbank** format and surrounded by useful links that we will ignore for the time being.

How many times does the term **PAX6** occur in this entry's annotation? _____

Move back to the **PAX6 GeneCard**.

Why might the number of **Additional mRNA** matches not match the number of **PAX6** transcripts? _____

Jump to the *Variants* section.

Sequence variations from dbSNP and Humsavar for PAX6 Gene ?						
SNP ID	Clin	Chr 11 pos	Sequence Context	AA Info	Type	MAF
rs1506 ^{5 43}	--	31,788,750(-)	ACAGC(A/T)GGGTG	G	utr-variant-3-prime	
rs592859 ^{5 43}	--	31,797,787(-)	TTATC(C/G)TGGGG	G	intron-variant	
rs608293 ^{5 43}	--	31,786,732(-)	ATGGT(A/G)AACAA	G	utr-variant-3-prime	
rs628224 ^{5 43}	--	31,797,626(+)	AGTTC(A/G)TTACT	G	intron-variant	
rs640258 ^{5 43}	--	31,792,182(-)	GCAGG(C/G)CCTCA	G	intron-variant	

Listed are the first **5** variations in the genomic region of **PAX6** according to the two variant databases **dbSNP** and **Humsavar**.

Click on the **See all** link to show all relevant variations. Move to the bottom of the list where you will find the, relatively few, **Humsavar** database entries. Follow one or two of the **Humsavar** links to arrive at pages from ExPASy in Switzerland.

What sort of variations are recorded in the **Humsavar** database? _____

The **dbSNP** variants are linked to corresponding **Ensembl** data, where such exists, by the superscript **5**. Try a couple of these links.

Note that all **SNPs** available from **dbSNP** are also available from **Ensembl**. Why might that be? _____

Filter with the term **rs358**. You should find three **dnSNP** database entries.

Sequence variations from dbSNP and Humsavar for PAX6 Gene ?						
SNP ID	Clin	Chr 11 pos	Sequence Context	AA Info	Type	MAF
rs35821697 ^{5 43}	--	31,797,364(+)	ACATT(C/T)TTATC	G	intron-variant	
rs35883677 ^{5 43}	--	31,794,440(+)	CACAC(-A)CACAC	G	intron-variant	
rs35840358 ^{5 43}	--	31,810,042(+)	AGAGC(C/G)CGGGG	G	intron-variant, utr-variant-5-prime	

Why might it be considered odd that **rs35883677** be included in **dbSNP**? _____

GeneCards provides links to entries that relate to **PAX6** in many other databases (e.g. **Ensembl**, **OMIM**). You can access entries in any of these databases from **GeneCards**. Mostly for later reference, note:

The **Ensembl** Accession Number for the **aniridia** gene (**Jump to the *Aliases* section**). _____

The number of human **PAX** genes (**Jump to the *Paralogs* section**). _____

What **Orthologues** exist in **Mouse** and **Drosophila** (**Jump to the *Orthologs* section**)? _____

What functions are suggested for **PAX6** (**Jump to the *Summaries* section** and/or **Jump to the *Function* section**)? _____

5 You will need to expand the display See All the **Additional mRNA sequences** before you can access the link you need. Sequences submitted to EMBL (Europe), Genbank (America) or DDBJ (DNA DataBase of Japan) are exchanged daily, so these sequences are not specific to GenBank.

6 Interpreting the accession code is not straight forward. The prefix letter(s) indicates the type of sequence and the database of first submission. The number before the full stop is there to make the code unique. The number after the full stop is a version number.

7 Search the web page for **PAX6** and ignore all hits in the web page annotation down the right of the page. Only hits in the data entry itself count.

To view the domain structure of the **PAX6** protein, **Jump to the Domains section**. In the **Protein Domains for PAX6 Gene** section, the **InterPro** and **Blocks** families to which **PAX6** belongs suggest a **Paired Box** domain⁸ at the N terminal, and a **Homeobox** domain.

Gene Families for PAX6 Gene
HGNC: **PAX** : Paired boxes, PRD class homeoboxes and pseudogenes

Protein Domains for PAX6 Gene
InterPro: Homeobox_CS , Homeobox_dom , Homeodomain-like , WHTH_DNA-bd_dom , Paired_dom
Blocks: Paired box protein, N-terminal
ProtoNet: P26367

Suggested Antigen Peptide Sequences for PAX6 Gene
GenScript: Design optimal peptide antigens: Paired box protein 6 isoform c (D1KF47_HUMAN), Paired box gene 6 (Aniridia, keratitis), isoform CRA_a (D3DQZ8_HUMAN), Paired box 6 (E5LBD7_HUMAN), Paired box protein Pax-6 (F1T0F8_HUMAN), Oculorhombin (PAX6_HUMAN) See All 15 »

Graphical View of Domain Structure for InterPro Entry P26367

UniProtKB/Swiss-Prot: PAX6_HUMAN : Contains 1 homeobox DNA-binding domain. Belongs to the paired homeobox family.

Domain: Contains 1 homeobox DNA-binding domain.
Contains 1 paired domain.
Family: Belongs to the paired homeobox family.

GenesLikeMe Genes that share domains with PAX6: [view](#) ?

Paired box protein Pax-6 (P26367)

Accession [P26367](#) (PAX6_HUMAN)
Species Homo sapiens (Human)
Length 422 amino acids (complete)

Source: UniProtKB

Protein family membership

None predicted.

Domains and repeats



Detailed signature matches

IPR001523	Paired domain		► SM00351 (PAX) ► PS00034 (PAIRED_1) ► PS51057 (PAIRED_2) ► PF00292 (PAX) ► PR00027 (PAIREDBOX)
IPR009057	Homeodomain-like		► G3DSA:1.10.10.60 ► SSF46689
IPR011991	Winged helix-turn-helix DNA-binding domain		► G3DSA:1.10.10.10
IPR001356	Homeobox domain		► PS50071 (HOMEBOX_2) ► PF00046 (Homeobox) ► SM00389 (HOX)
IPR017970	Homeobox, conserved site		► PS00027 (HOMEBOX_1)
no IPR	Unintegrated signatures		► PTHR24329 ► PTHR24329:SF294

Try the [Graphical View of Domain Structure for InterPro Entry P26367](#). This is a graphic generated by the **Interpro** database. See that the presence of the two main domains mentioned in the textual report is confirmed.

See the membership evidence for the two **Interpro** families that suggest a **Paired Box** followed by a **Homeobox**.

We will return here later for a closer look. For now, given that the **Signatures** whose identifiers begin **PS** represent **Prosite** matches and those beginning **PR** represent **Prints** matches. Can you explain:

Why there are two **Prosite** predictions for both the **Homeobox** and the **Paired Box** domains? _____

Why **Prints** appears to predict four very small **Paired box** domains instead of the single larger domain indicated by all the other predictions? _____



⁸ PAired boX (hence the name **PAX**) at the start (N terminal) of the protein. We investigate further later on.

Retrieving and Examining DNA Sequence Data

A good start would be to retrieve some of the DNA sequences that are associated with **PAX6**, the gene most associated with the disease **aniridia**, as was discovered from **GeneCards**. This could be done in a number of ways at any of several sites. The most popular choice must be to use **Entrez** at the **NCBI**.

First, go to the **Home Page** of the **The National Center for Biotechnology Information (NCBI)** (if necessary, try your **Bookmarks**, as a last resort, type in the **URL** “www.ncbi.nlm.nih.gov”).

You will arrive at a page offering access to the many **NCBI** resources available to you. Currently, you only require to search for **DNA** sequences, specifically those that relate to **aniridia**, so first set the database selection field of the **Search** facility at the top of your page to **Nucleotide**. and click on the **Search** button.

You are now offered the subset of **NCBI** resources specific to **Nucleotides**. You need to search the databases with more sophistication than the basic search offered, so click on the **Advanced** search option button.

Then in the **Nucleotide Advanced Search Builder**, change **All Fields** to **Title** in the pull down menu associated with the first search field and type in the keywords:

chromosome 11

In the second search field, again change **All Fields** to **Title** and type in the keyword:

You are asking **Entrez** to search for all **Nucleotide** database entries that contain the terms **chromosome 11** and **pax6** in the section of their annotation intended to be a succinct brief description (I.e. **Title**) of the entry. Click on the **Search** button to start the search going.

There is just one matching entry which is displayed before you in **Genbank** format, very neat!! It was the **DEFINITION** line that you searched by selecting the **Field** value **Title**. I needed a few tries to get the right search to find just what was needed, and was a bit surprised at the simplicity and accuracy of the final search. You are looking at a **RefSeqGene** (a subset of the **RefSeq** database) entry. As such, it represents a genomic sequence for a “well-characterised gene”, in this case **PAX6**.

Take a brief tour of the **FEATURES** for this entry and you will see that there are actually two genes associated with this sequence. **PAX6**, of course, and **ELP4** on the strand that is the complement of that represented here.

```
join(16551..16560,20128..20258,21186..21401,22106..22271,
28174..28332,28848..28930,29160..29310,29409..29524,
32102..32252,32943..33028)
/gene="PAX6"
/gene_synonym="AN; AN2; D11S812E; FVH1; MGDA; WAGR"
/note="isoform a is encoded by transcript variant 1;
paired box homeotic gene-6; oculorhombin; aniridia type II
protein"
/codon_start=1
/product="paired box protein Pax-6 isoform a"
/protein_id="NP_000271.1"
/db_xref="GI:4505615"
/db_xref="CCDS: CDS31451.1"
/db_xref="GeneID: 5080 "
/db_xref="HGNC: HGNC:8620 "
/db_xref="MIM: 607108 "
/translation="MONSHGVNQLGGFVNVGRPLPDSTROKIVELAHSGARPDISR
ILQVSMNGCVSKILGRYYETGSIRPRAIGGSKPRVATPEVVKIAQYKRECPISIFWEI
RDRLLSEGVTNDNIPVSSINVRVLNLASEKQQMGAQDMYDQLRMLNGQTGWSGTRP
GWPGTGTVPQOPTQDGCGQQEGGENTNISSSNGEDSDEAQMRLOLKRKLQRNRRTSFT
QEQUIALEKEFERTHYDPVAFERLAALKDLPARIQWVFSNRAKWRREKLRNQRR
QASNTPSHIPISSSTSVYQPIPQPTTPVSSFTSGSMLGRTDTALTNTYSALPPMPS
FTMANLPMQPPVPSQTSYSCMLPTSPSVNGRSYDTYTPPHMQTHMNSQPMGTSGTT
STGLISPGVSPVQVPGSEPDMQSYWPRLQ"
```

gene	5001..38170 /gene="PAX6" /gene_synonym="AN; AN2; D11S812E; MGDA; WAGR" /note="paired box 6" /db_xref="GeneID:5080" /db_xref="HGNC:8620" /db_xref="MIM: 607108 "
gene	complement(38437..>40170) /gene="ELP4" /gene_synonym="AN; C1orf19; dJ68P15A.1; hELP4; PAX6NEB; PAXNEB" /note="elongator acetyltransferase complex subunit 4" /db_xref="GeneID: 26610" /db_xref="HGNC: HGNC:1171" /db_xref="MIM: 606985"

At the top of your page, **Analyze this sequence** by clicking on the **Highlight Sequence Features** option. The **CoCoding Sequence (CDS)** feature for **PAX6** is displayed for you by highlighting the relevant parts (the coding **exons**) of the sequence and displaying the **CDS** details including the DNA regions that need to be **joined** to form the **CDS** and the **translation** of the **CDS**.

Use the controls at the bottom of your page to look at the other features of this entry (select feature **number** and then click on the **Feature** button).

What were the features that you found? _____

Why might you have expected more features than there were? _____

COMMENT	REVIEWED REFSEQ : This record has been curated by NCBI staff in collaboration with Isabel Hanson, David FitzPatrick. The reference sequence was derived from Z95332.1 and Z83307.1 . This sequence is a reference standard in the RefSeqGene project.			
PRIMARY	REFSEQ_SPAN 1-18852 18853-40170	PRIMARY IDENTIFIER Z95332.1 Z83307.1	PRIMARY_SPAN 2023-20874 105-21422	COMP

Take a look at the **COMMENT** and **PRIMARY** sections just above the **FEATURES**. This entry is suggested to be constructed from two sequences from **GenBank**. That is, the products of two sequencing projects.

Take a quick look at the **GenBank** entries by entering their **ACCESSION** numbers into the **Search** box at the top of your page. Click on the **Search** button.

Nucleotide	Z95332 Z83307
Limits	Advanced

- [Human DNA sequence from clone CFAT5 on chromosome 11, complete sequence](#)
 1. 20,874 bp linear DNA
Accession: Z95332.1 GI: 2190397
[GenBank](#) [FASTA](#) [Graphics](#)
 2. 22,253 bp linear DNA
Accession: Z83307.1 GI: 1730464
[GenBank](#) [FASTA](#) [Graphics](#)

Lo and behold, the two **GenBank** entries are summoned forth. Take a look at one or both. Not particularly illuminating I think⁹. These are clones sequenced as part of the **Human Genome Project (HGP)**. They served to cover regions of **Chromosome 11** and have little biological significance in themselves.

Move back to the list, as illustrated. Elect to **Analyze these sequences**, selecting from the extensive range of possibilities **Run BLAST**. We will look at **blast** properly later, the idea here is to simple prove that these two sequencing clones really do overlap in the fashion suggested by the evidence so far. So, elect to **Align two or more sequences**¹⁰. Cut and paste one of the sequencing clone **accession numbers** from the **Enter Query Sequence** box to the **Enter Subject Sequence** section of the form. Elect to **Show results in a new window**¹¹. Firmly address the **BLAST** button.

BLASTN programs search nucleotide subjects using a nucleotide query. [more...](#)

Enter Query Sequence [Clear](#) [Query subrange](#)

Enter accession number(s), gi(s), or FASTA sequence(s) [?](#)

Or, upload file [?](#)

Job Title Enter a descriptive title for your BLAST search [?](#)

Align two or more sequences [?](#)

Enter Subject Sequence [Clear](#) [Subject subrange](#)

Enter accession number, gi, or FASTA sequence [?](#)

Or, upload file [?](#)

Program Selection

Optimize for Highly similar sequences (megablast) More dissimilar sequences (discontiguous megablast) Somewhat similar sequences (blastn)
Choose a BLAST algorithm [?](#)

BLAST Search nucleotide sequence using Megablast (Optimize for highly similar sequences) Show results in a new window

Just one region of overlap should be identified.

```
Query 20771 GATCCGGAGCGACTTCCGCCTATTCCAGAAAATTAAAGCTCAAACCTTGACGTGCAAGCTAGT 20830
Sbjct 1 GATCCGGAGCGACTTCCGCCTATTCCAGAAAATTAAAGCTCAAACCTTGACGTGCAAGCTAGT 60
Query 20831 TTTATTTAAAGACAATGTCAGAGAGGCTCATCATATTTCCC 20874
Sbjct 61 TTTATTTAAAGACAATGTCAGAGAGGCTCATCATATTTCCC 104
```

How does the alignment you generated match up with the annotation of the original **RefSeq** entry you discovered? __

- 9 The annotation is very sparse which makes these entries very hard to find directly. The **EML-Bank** versions include some links to the **Ensembl** codes you identified when looking at **GeneCards**. These would have been helpful but are not part of the official International Nucleotide Sequence Database Collaboration (INSDC) annotation that should be consistent between **GenBank**, European Nucleotide Archive (ENA), which includes **EML-Bank**, and **DNA Data Bank of Japan (DDBJ)**.
- 10 As opposed to comparing each of the two clones against an entire sequence database.
- 11 Just because its neater. In my, significantly less then humble, opinion anyway.

Now for an entirely new search. The easiest way to get a fresh start is to move back to your browser tab displaying the **GenBank** Search results, and then click on the **Advanced** option of the **Search** facility at the top of the page. You should arrive back at the **Nucleotide Advanced Search Builder** offering a fresh start.

<input type="text" value="Title"/>	<input type="text" value="pax6"/>
<input checked="" type="radio"/> AND	<input type="text" value="Organism"/>
	<input type="text" value="human"/>

Set up a new search as illustrated and set it going. Ultimately simple this time. You have requested all **Human** sequences that are centrally associated with the gene **PAX6**.

You should achieve a list of **60** or so sequences, all clearly claiming **PAX6** association and most proclaiming their humanity loudly in Latin.

Summary: 200 per page Sort by Default order
Items per page:
Iter 5 10 20 50 100 200
1. 7379
[n antisense R](#)
Summary: 200 per page Sort by Accession
Items: 63
1. Synthetic constr. stop codon, in Fl.
1,283 bp linear of Accession: AB5283e

You will have more hits than can be displayed in one go. Also, the hits are arranged in a “**Default**” order which has thus far defied all my attempts to associate with any definition of logic!

To deal with both of these issues, use the display control pull down menus at the top of your page to set the items **per page** to something big and the **Sort by** option to something sane.

The list shows matches between the terms entered and the **annotation** of DNA sequences. Not all relevant sequences will be present. For example, the **mRNA** with accession number **BX640762** was justifiably referenced in the **PAX6 Genecard** will not be in this list. **PAX6** appears nowhere in the entire annotation of **BX640762** let alone just its **DESCRIPTION** (or **Title**) field.

A little way down the list you should see two primer sequences. Their **Descriptions** suggest they are a pair of PCR primers used for picking out the **PAX6** gene. Select both by clicking in their selection boxes.

```

LOCUS AJ270357      25 bp   DNA    linear  PRI 26-JUL-2000
DEFINITION Homo sapiens paired box gene 6 (PAX6), isoform a sense primer.
ACCESSION AJ270357
VERSION AJ270357.1 GI:9557932
KEYWORDS .
SOURCE Homo sapiens (human)
ORGANISM Homo sapiens
Eukaryota; Metazoa; Chordata; Craniata; Vertebrata; Euteleostomi; Mammalia; Eutheria; Earchontoglires; Primates; Haplorrhini; Catarrhini; Hominidae; Homo.
REFERENCE 1 (bases 1 to 25)
AUTHORS Palm,K., Salin-Nordstrom,T., Levesque,M.F. and Neuman,T.
TITLE Fetal and adult human CNS stem cells have similar molecular characteristics and developmental potential
JOURNAL Brain Res. Mol. Brain Res. 78 (1-2), 192-195 (2000)
PUBMED 10891600
REFERENCE 2 (bases 1 to 25)
AUTHORS Palm,K.
TITLE Direct Submission
JOURNAL Submitted (04-OCT-1999) Surgery, Cedars Sinai Medical Center, 8700 Beverly Blvd., Los Angeles, CA 90048, US
COMMENT Related entry: NM_000280.
FEATURES Location/Qualifiers
source 1..25
/organism="Homo sapiens"
/mol_type="genomic DNA"
/db_xref="taxon:9606"
misc_feature 1..25
/note="PCR sense primer for paired box gene 6 (PAX6),
isoform a"
ORIGIN 1 ccagccagag ccagcatgc gaaca
//
```

- [Homo sapiens neuroretina-specific pax6 gene enhancer region](#)
- 7. 267 bp linear DNA
Accession: AJ009907.1 GI: 3378599
[GenBank](#) [FASTA](#) [Graphics](#)
- [Homo sapiens paired box gene 6 \(PAX6\), isoform a sense primer](#)
- 8. 25 bp linear DNA
Accession: AJ270357.1 GI: 9557932
[GenBank](#) [FASTA](#) [Graphics](#)
- [Homo sapiens paired box gene 6 \(PAX6\), isoform a antisense primer](#)
- 9. 26 bp linear DNA
Accession: AJ270358.1 GI: 9557933
[GenBank](#) [FASTA](#) [Graphics](#)
- [Homo sapiens paired box protein PAX6 \(PAX6\) mRNA, complete cds](#)
- 10. 1,399 bp linear mRNA
Accession: AY047583.1 GI: 15422112
[GenBank](#) [FASTA](#) [Graphics](#)

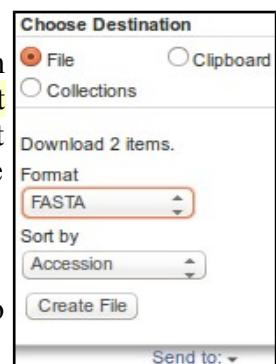
Click on the **sense primer**. Properly, you would read all the **References** carefully. Instead, note the length looks about right and return to your list with the **Back** button.

It will be good to investigate these primers later, so find the diminutive **Send to:** button which is near the bottom of your page and use it. Choose your **Destination** to be **File** and set the **Format** of that file to be **FASTA**. Strike the **Create File** button with a firm and confident click of your every ready mouse. With irritating presumption, the choice of file name is made for you. Your sequences are stored in a file named:

sequence.fasta

The **NCBI** is justifiably not famed for its understanding of poetry! Do whatever it takes to rename this file to be called:

pax6_primers.fasta



Retrieving and Examining Protein Sequence Data

For protein sequences, we will move from the **NCBI** and use **UniprotKB**. First move to the home of **UniProtKB** (www.uniprot.org).

Enter the **GenBank** accession number **Z83307** that you discover at the **NCBI** into the **Query** box at the top of your page and then click the button.

You should achieve a list of around **10** protein sequences all associated with the genes **PAX6** and **ELP4**. Most of the list will be **unreviewed** entries from **UniProtKB/TrEMBL**.

To simplify, click on the button that reduces the list to just the **Reviewed** entries from **UniProtKB/Swiss-Prot**.

Entry	Entry name	Protein names	Gene names	Organism	Length
P26367	PAX6_HUMAN	Paired box protein Pax-6 (Aniridia type II protein) (Ocularhombin)	PAX6, AN2	Homo sapiens (Human)	422
Q96EB1	ELP4_HUMAN	Elongator complex protein 4 (hELP4) (PAX6 neighbor gene protein)	ELP4, C11orf19, PAXNEB	Homo sapiens (Human)	424

Increase the information in the **Protein names** column by clicking the button.

Where have you seen these genes mentioned previously?

Now edit the contents of the **Query** box to be both the **Genbank** accession numbers that you discovered at the **NCBI** joined by the boolean operator **OR** and then click the button.

Q15293	RCN1_HUMAN	Reticulocalbin-1	RCN1, RCN	Homo sapiens (Human)	331
HOYER5	HOYER5_HUMAN	Reticulocalbin-1	RCN1	Homo sapiens (Human)	57
HOYDA4	HOYDA4_HUMAN	Reticulocalbin-1	RCN1	Homo sapiens (Human)	28
E9PLM2	E9PLM2_HUMAN	Reticulocalbin-1	RCN1	Homo sapiens (Human)	20
E9PP27	E9PP27_HUMAN	Reticulocalbin-1	RCN1	Homo sapiens (Human)	58

Your list of hits should be a little longer this time. Order the list by by clicking in the appropriate column heading. The extra proteins should be at the bottom of your list associated with a third gene to which introductions are still pending. Meet **RCN1**. Note that all but one of the proteins associated with this gene are **unreviewed**.

These entries are in **UniProtKB/TrEMBL** (indicated with a as opposed to a which indicates a **reviewed UniProtKB/Swiss-Prot** protein).

For a nice tidy list, again click on the button that reduces the list to just the **Reviewed** entries from **UniProtKB/Swiss-Prot**.

Entry	Entry name	Protein names	Gene names	Organism	Length
Q96EB1	ELP4_HUMAN	Elongator complex protein 4 (hELP4) (PAX6 neighbor gene protein)	ELP4, C11orf19, PAXNEB	Homo sapiens (Human)	424
P26367	PAX6_HUMAN	Paired box protein Pax-6 (Aniridia type II protein) (Ocularhombin)	PAX6, AN2	Homo sapiens (Human)	422
Q15293	RCN1_HUMAN	Reticulocalbin-1	RCN1, RCN	Homo sapiens (Human)	331

How is that this is the first occasion that the gene **RCN1** has been apparent?

How is it that we have found any protein sequences at all by looking at the barren annotation of the two clones **Z83307** and **Z95332**?

Select the entry **PAX6_HUMAN** by clicking in the selection box on the extreme left.

Click on the button near the top of your page. Ensure **Uncompressed** is selected, as illustrated, and click on the button. Do whatever it takes to get the canonical isoform of the selected sequence into a file on your **Desktop** called:

pax6_human.fasta

Deselect the entry **PAX6_HUMAN**. Click on the Accession number (**P26367**) to view the database entry for the protein you have just saved to file in all its **UniProtKB** splendour.

Note the navigation bar down the left hand side of the entry that enables easy access to the various sections of the database record.

Move to the **Entry information** section.

Entry information	
Entry name	PAX6_HUMAN
Accession	Primary (citable) accession number: P26367 Secondary accession number(s): Q6N006, Q99413

Make a note of the first **UniProtKB Accession number** for the **PAX6** protein. _____

Why do you suppose there is more than one **Accession number** for this protein? _____

Make a note of the **UniProtKB Identifier** (or entry name)¹²? _____

Move to the **Family & Domains** section.

Look in the **Domains and Repeats** section for the two major domains suggested by **GeneCards**. Only the **Paired** box **Domain** is present?

Family & Domains				
Domains and Repeats				
Feature key	Position(s)	Length	Description	Graphical view
Domain ⁱ	4 – 130	127	Paired PROSITE-ProRule annotation	
Compositional bias				
Feature key	Position(s)	Length	Description	Graphical view
Compositional bias ⁱ	131 – 209	79	Gln/Gly-rich	
Compositional bias ⁱ	279 – 422	144	Pro/Ser/Thr-rich	

Now move to the **Function** section. Look in the **Regions** section.

Regions				
Feature key	Position(s)	Length	Description	Graphical view
DNA binding ⁱ	210 – 269	60	Homeobox PROSITE-ProRule annotation	

You should see the **Homeobox** recorded as a **DNA binding Functional** region. Both the **Paired** box and the **Homeobox** are, of course, **Domains** and both are **DNA binding Functional** regions. It is messy that one is listed as a **Domain**, the other as **DNA binding**¹³? Nevertheless ...

What are the start and end positions of the **Paired** domain? _____

What are the start and end positions of the **Homeobox** domain? _____

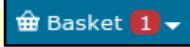
Note the range of the **Proline, Serine, Threonine** rich region at the end of the protein. _____

12 UniprotKB still sometimes uses 2 names for each entry, an **Identifier** and an **Accession** code.

13 Apparently, the reasons are “Historic”?

Whilst you have it in view, download the sequence of just the **Homeobox** region for analysis later on. The way to do this involves baskets? As in shopping baskets? OK, ours not to reason why ... just do whatever works. In this instance, click on the associated with the **Homeobox** region.

Go to the top of the page and click on .



Select the only entry.

<input checked="" type="checkbox"/>	Entry	Entry name	Organism	Remove
<input checked="" type="checkbox"/>	P26367[210-269]	PAX6_HUMAN	Homo sapiens (Human)	

Click on the button. Accept the default settings as illustrated and click on the button.

Download selected (1)
 Download all (1)

Format:

Compressed Uncompressed

Do whatever it takes to get the **Paired** box sequence into a file on your **Desktop** called:

homeobox_domain.fasta

Finally, open up the file you just created in an appropriate text editor and change the first line¹⁴ from:

>sp|P26367|210-269

to

>Homeobox-Domain P26367 (210-269)

It would also be good to save the **Paired** box region for later analysis whilst it is nearby. So move once more to the

Feature key	Position(s)	Length	Description	Graphical view	Feature Identifier	Actions
Domain ¹	4 - 130	127	Paired			

Family & Domains section. Click on the associated with the **Paired** box **Domain**.

Go up the page and click on .

<input checked="" type="checkbox"/>	Entry	Entry name	Organism	Remove
<input type="checkbox"/>	P26367[210-269]	PAX6_HUMAN	Homo sapiens (Human)	
<input checked="" type="checkbox"/>	P26367[4-130]	PAX6_HUMAN	Homo sapiens (Human)	

Select the **Paired** box entry only.

Download selected (1)
 Download all (2)

Format:

Compressed Uncompressed

Click on the button. Accept the default settings as illustrated and click on the button.

Do whatever it takes to get the **Paired** box sequence into a file on your **Desktop** called:

pax_domain.fasta

As for the **Homeobox** file, open up the new file in an appropriate text editor and change the first line from:

>sp|P26367|4-130

to

>Pax-Domain P26367 (4-130)

To complete the job tidily, Click on the button to empty your **Basket**. Confirm that you *really really* want to tip all the **entries** out of the stupid **Basket**. Enough shopping for today?!?

¹⁴ Not strictly necessary, to be honest. However, the | symbol occasionally causes problems, so I suggest removing it.

Consider next the **Pathol./Biotech** section. In particular, the **Natural variants**.

The mention of **AN** in the description implies that this variant is a cause for the disease **Aniridia**. All the variants recorded here are described as causal for either **AN** or **PETAN**. **PETAN** refers to another disease (**Peters anomaly**).

One might suppose that **all** the variants recorded as substitutions¹⁵ must **all** be associated with one or more SNP(s) in the genome.

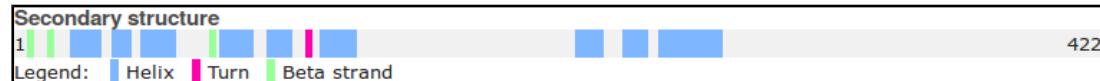
Feature key	Position(s)	Length	Description	Graphical view	Feature identifier
Natural variant ⁱ	17 – 17	1	N → S in AN. 1 Publication		VAR_003808
Natural variant ⁱ	18 – 18	1	G → W in AN. 1 Publication		VAR_003809
Natural variant ⁱ	19 – 19	1	R → P in AN. 1 Publication		VAR_047860
Natural variant ⁱ	22 – 26	5	Missing in AN. 2 Publications		VAR_008693
Natural variant ⁱ	26 – 26	1	R → G in PETAN. 2 Publications		VAR_003810
Natural variant ⁱ	29 – 29	1	I → S in AN. 1 Publication		VAR_008694
Natural variant ⁱ	29 – 29	1	I → V in AN. 1 Publication		VAR_003811
Natural variant ⁱ	33 – 33	1	A → P in AN. 1 Publication		VAR_008695
Natural variant ⁱ	37 – 39	3	Missing in AN. 1 Publication		VAR_008696

However, only the **Natural variantⁱ** variation at **375** is associated with a **dbSNP** entry?

Why do you suppose this is the case? _____

Click on the **A → P** link associated with position **33**. This substitution is the disease causing **Natural variant** that is the focus of many of the exercises that follow. You will be taken to entry **VAR_008695** of a variant database (glanced at when considering **Humsavar** whilst looking around **GeneCards**) at **ExPasy** in Switzerland (to be revisited). This entry very probably represents a short cut to much we will more ponderously discover by other means. Too easy!! take a quick look and then move back to **PAX6_HUMAN**.

Move to the **Structure** section.



Click on the **Show more details** button.

Feature key	Position(s)	Length	Description	Graphical view
Beta strand ⁱ	6 – 8	3	Combined sources	
Beta strand ⁱ	14 – 16	3	Combined sources	
Helix ⁱ	23 – 34	12	Combined sources	
Helix ⁱ	39 – 46	8	Combined sources	
Helix ⁱ	50 – 63	14	Combined sources	
Beta strand ⁱ	77 – 79	3	Combined sources	
Helix ⁱ	81 – 93	13	Combined sources	
Helix ⁱ	99 – 108	10	Combined sources	
Turn ⁱ	114 – 116	3	Combined sources	
Helix ⁱ	120 – 133	14	Combined sources	
Helix ⁱ	219 – 229	11	Combined sources	
Helix ⁱ	237 – 246	10	Combined sources	
Helix ⁱ	251 – 275	25	Combined sources	

Describe the arrangement of Helices within **PAX6**. _____

Note the start position of the middle helix of each set of three. _____

Note the end position of the third helix of each set of three. _____

Note the position of the Beta strands relative to the helix groups. _____

15 That is, all but those at positions 22-26 and 37-39, which are **deletions**.

Click on the link to the **Sequences** section. This section confirms the **Uniprot** isoform count of 3 recorded in **GeneCards**.

The sequence of **Isoform 1**, the 'canonical' sequence, is the one you will have saved in a file called **pax6_human.fasta**. Having admired this sequence, displayed by default, send it away by clicking on the nearest **« Hide** button.

The second isoform, **Isoform 5a**, is shown here to have **14** extra amino acids after position **47** (a **Q**) of the canonical sequence.

The **3rd** isoform, **Isoform 3**, declares "The sequence of this isoform is not available", indicating that although the literature records Western blots suggesting a third protein product¹⁶, the protein sequence has yet to be determined.

Compare the two isoforms with sequence. Click on the **Align** link¹⁷. The best isoform alignment is computed and displayed by **ClustalW**, a popular tool for aligning sequences, that you will use again later. The isoforms are extremely similar. The alignment highlights the only difference well. The extra amino acids in the second isoform are clear to see. Experiment with the **Annotation** possibilities. I choose to show the two major domains and the helices, showing clearly the way the helix triplets are arranged in the **PAX** and **Homebox** domains.

P26367	PAX6_HUMAN_1	MQNSHSGVNOLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQ-----	47	Annotation
P26367-2	PAX6_HUMAN_1	MQNSHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQTHADAKVQVLDNQ*****	60	<input type="checkbox"/> Turn <input type="checkbox"/> Alternative sequence <input type="checkbox"/> Beta strand <input type="checkbox"/> Chain <input checked="" type="checkbox"/> Helix <input checked="" type="checkbox"/> Domain <input type="checkbox"/> Compositional bias <input type="checkbox"/> Sequence conflict <input checked="" type="checkbox"/> DNA binding <input type="checkbox"/> Natural variant
P26367	PAX6_HUMAN_48	-VSNGCVSKILGRYYETGSIRPRAIGGSKPRVATPEVVSKIAQYKRECPEIFAWEIRDRL	106	
P26367-2	PAX6_HUMAN_61	NVSNGCVSKILGRYYETGSIRPRAIGGSKPRVATPEVVSKIAQYKRECPEIFAWEIRDRL*****	120	
P26367	PAX6_HUMAN_107	LSEGVCCTNDNIPSVSSINRVLRNLASEKQQMGADGMYDKLRLMLNGQTGSWGTRPGWYPGT	166	
P26367-2	PAX6_HUMAN_121	LSEGVCCTNDNIPSVSSINRVLRNLASEKQQMGADGMYDKLRLMLNGQTGSWGTRPGWYPGT*****	180	
P26367	PAX6_HUMAN_167	SVPGQPTQDGCQQEGGGENTNSISSNGEDSDEAQMRLQLKRKLQRNRRTSFTQEQUIALE	226	
P26367-2	PAX6_HUMAN_181	SVPGQPTQDGCQQEGGGENTNSISSNGEDSDEAQMRLQLKRKLQRNRRTSFTQEQUIALE*****	240	
P26367	PAX6_HUMAN_227	KEFERTHYPDVFARERLAAKIDLPEARIQVWFNSNRRAKWRREEKLRNQRQASNTPSHIP	286	
P26367-2	PAX6_HUMAN_241	KEFERTHYPDVFARERLAAKIDLPEARIQVWFNSNRRAKWRREEKLRNQRQASNTPSHIP*****	300	
P26367	PAX6_HUMAN_287	ISSSFSTSVYQPIPQPTTPVSSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPP	346	
P26367-2	PAX6_HUMAN_301	ISSSFSTSVYQPIPQPTTPVSSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPP*****	360	
P26367	PAX6_HUMAN_347	VPSQTSSYSCMLPTSPSVNGRSYDTYTPPHMQTHMNSQPMGTSGLISPVGVSVPQ	406	
P26367-2	PAX6_HUMAN_361	VPSQTSSYSCMLPTSPSVNGRSYDTYTPPHMQTHMNSQPMGTSGLISPVGVSVPQ*****	420	
P26367	PAX6_HUMAN_407	VPGSEPDMSQYWPRLO	422	
P26367-2	PAX6_HUMAN_421	VPGSEPDMSQYWPRLO	436	

Describe the arrangement of Helices within the two major domains of **PAX6**.

16 "No experimental evidence..." in this section means that the splice variant is only identified as a result of a match with a single cDNA or EST which is regarded as insufficient to assign an amino acid translation. All **UniProt/SwissProt** splice variants supported by matches with 2 or more cDNA/ESTs are checked to ensure they are not actually just errors due to frameshifts, intron retention etc.

17 The Select button allows choice of isoforms. Redundant here as we wish to compute an alignment of the only two isoforms of known sequence.

Move back to the page showing P26367. You should still have the **Sequences** section in view.

Note the extra sequence in **P26367-2** and where it starts: _____

Move to the **Cross-references** section and see that the names of several relevant sequences are recorded, including the genomic two genomic sequencing clones.

Select the link destinations:	M77844 mRNA. Translation: AAA59962.1 .
<input checked="" type="radio"/> EMBL ⁱ	M93650 mRNA. Translation: AAA36416.1 .
<input type="radio"/> GenBank ⁱ	AY047583 mRNA. Translation: AAK95849.1 .
<input type="radio"/> DDBJ ⁱ	BX640762 mRNA. Translation: CAE45868.1 .
	Z95332 , Z83307 Genomic DNA. Translation: CAG38363.1 .
	Z83307 , Z95332 Genomic DNA. Translation: CAG38087.1 .
	BC011953 mRNA. Translation: AAH11953.1 .

How would you rationalise the reference to the mRNA entry **BX640762** here? _____

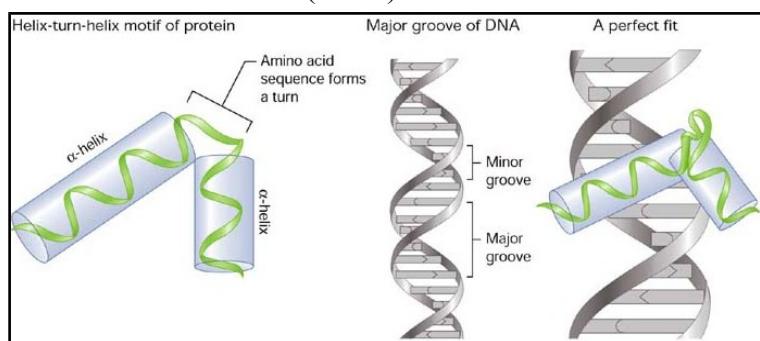
PROSITE ⁱ	PS00027. HOMEOBOX_1. 1 hit.
	PS50071. HOMEOBOX_2. 1 hit.
	PS00034. PAIRED_1. 1 hit.
	PS51057. PAIRED_2. 1 hit.
	[Graphical view]

At the bottom of the **Cross-references** section are links to **Family and domain databases**, including PROSITE database. Click on the link to the third PROSITE entry down, the first for **PAIRED**.

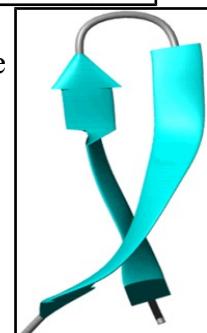
You will be presented with the documentation page for the **PROSITE** pattern for a **Paired domain** at the top of which is a general

Description of a Paired domain. I found this quite a difficult read. My summary of the parts of the message relevant to these exercises is:

- A **Paired domain** is about 126 amino acids long
- It is generally found at the beginning of a protein
- It is often followed by a homeodomain (as here) and/or an octopeptide (of unspecified properties?)
- There is often a **Pro-Ser-Thr-rich C-terminus** (as in this case)
- A paired domain is a DNA binding domain that has 2 binding regions each of which involves a helical triplet
- The second and third helices of each helical triplet form **helix-turn-helix (HTH) motifs**



- The **HTH** regions bind the DNA major groove¹⁸



- The first helical triplet is preceded by a **beta-turn** and **beta-hairpin** ("wing") that participate in the DNA binding
- The linker region between the two helical triplets can bind the **DNA minor groove**

All of these properties have already been suggested and/or will be discovered variously as the exercise progresses.

¹⁸ If, like me, you have conceptual problems with major and minor grooves. Try this [animated picture](#). Helped me at least. As did the image above.

Move down to the **Technical section**. PROSITE stores representations of conserved protein features (**motifs**). It uses two methods. One requires a bit of thought, but the other is quite intuitive. That which you are now considering is a simple **Consensus pattern** defined clearly at the top of this section. The suggestion here is that this pattern is to be found in all known **Paired domain** sequences¹⁹.

Technical section

PROSITE methods (with tools and information) covered by this documentation:

PAIRED_1, PS00034; Paired domain signature (PATTERN)

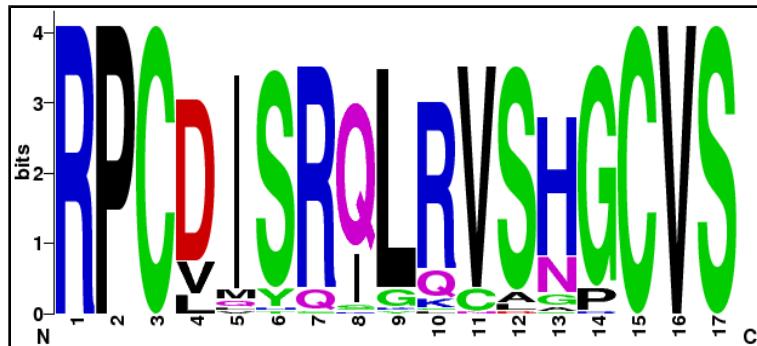
- Consensus pattern:
R-P-C-x(11)-C-V-S
- Sequences in UniProtKB/Swiss-Prot known to belong to this class: 58
 - detected by PS00034: 58 (true positives)
 - undetected by PS00034: 0 (false negative or 'partial')
- Other sequence(s) in UniProtKB/Swiss-Prot detected by PS00034: 7 false positives.

What is the **Consensus pattern** for a **Paired domain**? _____

Where in a **Paired domain** should the **Consensus pattern** occur? _____

How would you interpret this **Consensus pattern**? _____

How effective does the **Technical section** imply this pattern to be? _____



There are a number of links to follow here. I would suggest you [Retrieve the sequence logo from the alignment](#). The logo is representing the degree to which each position of the **Consensus pattern** is conserved and how. The higher the letter, the more prominent is that letter in that position²⁰. The particular value of the logo here is to illustrate that the region of the **Consensus pattern** is not only conserved over the 3 positions at either end. It is well conserved over its entire length. Not well enough, however, to be described effectively

using such a simplistic strategy as this sort of **Consensus pattern**.

Move back and up to the **Description of a Paired domain**. Follow the link to the **Prosite** documentation for **homeobox** embedded here ([PDOC00027](#)) .

How well does the secondary structure suggested by **Prosite** match that recorded by **Uniprot**? _____

How many **helix-turn-helix** motifs would you expect in the **homeobox** domain? _____

Where (in amino acid positions) would you expect all the **PAX6 HTH** motifs to be? _____

19 This is not strictly true, as you will discover later.

20 A fuller description is provided from the **Logo** page. Click on the **More...** link.

Pfamⁱ PF00046. Homeobox. 1 hit.
PF00292. PAX. 1 hit.
[Graphical view]

Move back to the page displaying the UniprotKB/SwissProt entry for the human **PAX6** protein. Find the **Pfam** links in the **Family and domain databases** section (use the **Cross-references** button again if necessary). Unsurprisingly, there are two links to **Pfam**.

The **Pfam** database is a collection of protein domain families. Each family is represented by multiple sequence alignments and Hidden Markov Models (HMMs)²¹. There are two levels of quality to **Pfam** families: **Pfam-A** (based on manual annotated seed alignments, high quality) and **Pfam-B** (automatically generated, lesser quality)²².

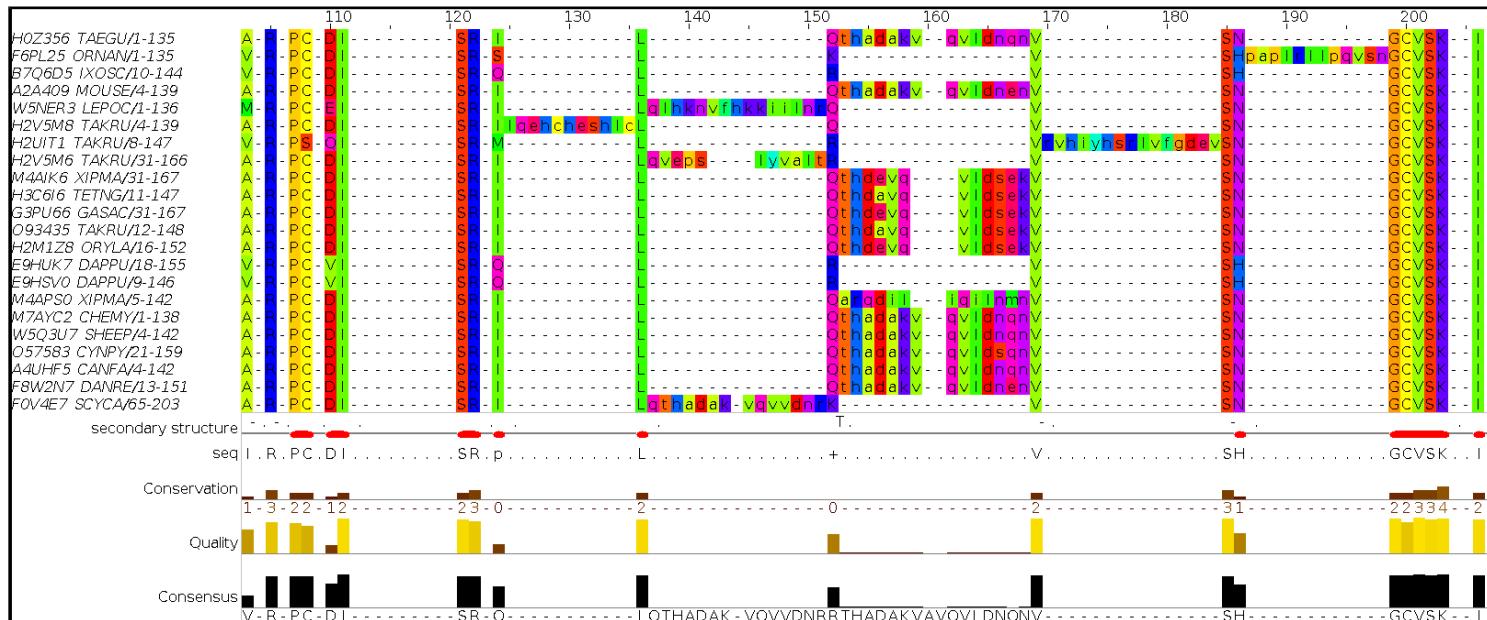
Click on the accession code for the **Pfam** entry for **PAX** (**PF00292**). The requested **Pfam** entry will be displayed²³. From this page you can view much **PAX** related information in other databases. For now, click on the **Alignments** link on the left of the page. In the **View options** section, click on the tick in the **Full** column of the

	Seed (5)	Full (2076)	Representative proteomes				NCBI (3555)	Meta (5)
			RP15 (225)	RP35 (408)	RP55 (722)	RP75 (955)		
Jalview	✓	✓	✓	✓	✓	✓	✓	✓
HTML	✓	✓	✓	✓	✓	✓	✗	✗
PP/heatmap	✗ ¹	✓	✓	✓	✓	✓	✗	✗
Pfam viewer	✓	✓	✗	✗	✗	✗	✗	✗

¹Cannot generate PP/Heatmap alignments for seeds; no PP data available

Key: ✓ available, ✗ not generated, — not available.

Jalview²⁴ Row. In the window that will thrust its way onto your screen will appear an alignment of all the **PAX** domains of the **Pfam-A** entry displayed by the **Jalview** applet.



More **Jalview** functionality is available when running **Jalview** via **Java Web Start**. To achieve this, click on the **start Jalview** button. In yet another window, you should now see the same alignment even more garishly coloured for your delight²⁵. Use the scroll bar on the right to scroll up and down the full set. The **Seed** alignment for this family is carefully constructed and manually curated, however the **Full** alignment is transparently not. The alignment is automatically generated by a program called **HMMER3**. The alignment includes a number of **PAX** domains that align badly at the beginning. This is a shame as it makes known features difficult to locate.

The alignment shown above required some editing. Details are in the answers to the next two questions.

Allowing for the distorted numbering of the alignment, how would you interpret the extra 14 or so amino acids that some sequences appear to have around position 150-170?

How might you interpret the way that **HMMER3** suggests that just one or two sequences have a similar insertion in a slightly different place to its neighbouring proteins?

21 HMMs are essentially mathematical representations of the alignments. Not very pretty for humans to look at, but currently considered the best way to present an alignment to a computer program so that alignments can be compared with each other and/or other protein sequences.

22 For a more complete description of **Pfam** go to: <http://pfam.sanger.ac.uk/help>.

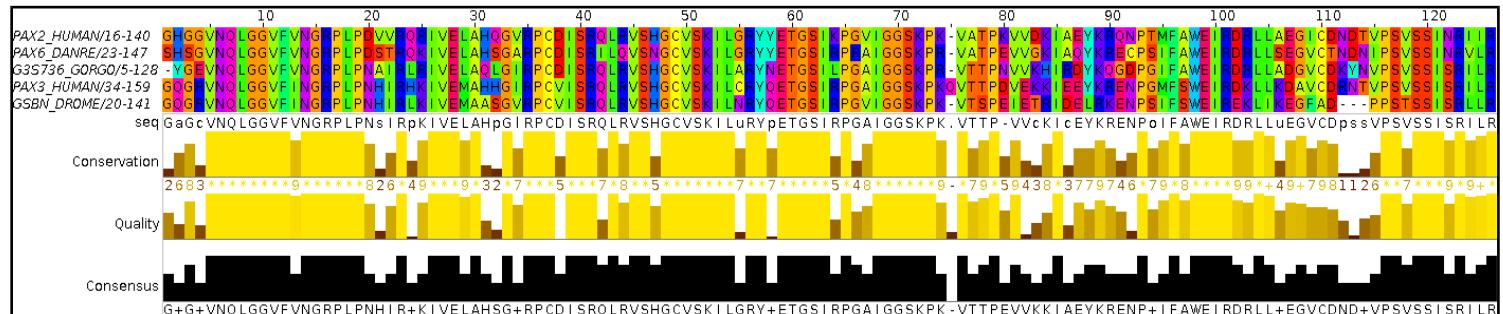
23 It is a **Pfam-A** entry, they all have accession codes starting **PF**. **Pfam-B** accession codes start **PB**.

24 A very nice Java tool for viewing alignments that we will use again.

25 On some systems, there can be problems getting **Java Web Start** to behave properly. Ask if you have any difficulty.

For a more restrained view, move back to the **Pfam PAX** entry page, move back to the **Pfam PAX** entry page. In the **View options** section, click on the tick in the **Seed** column of the **Jalview Row**.

Click on the **start Jalview** button to start the **Java Web Start** version of **Jalview**. In view are the aligned sequences of the **Seed** alignment from which the profile **HMM** for **PAX** is calculated. None of the **5** seed sequences include the **14** extra amino acids noted previously²⁶. Human **PAX6** is not a seed sequence.

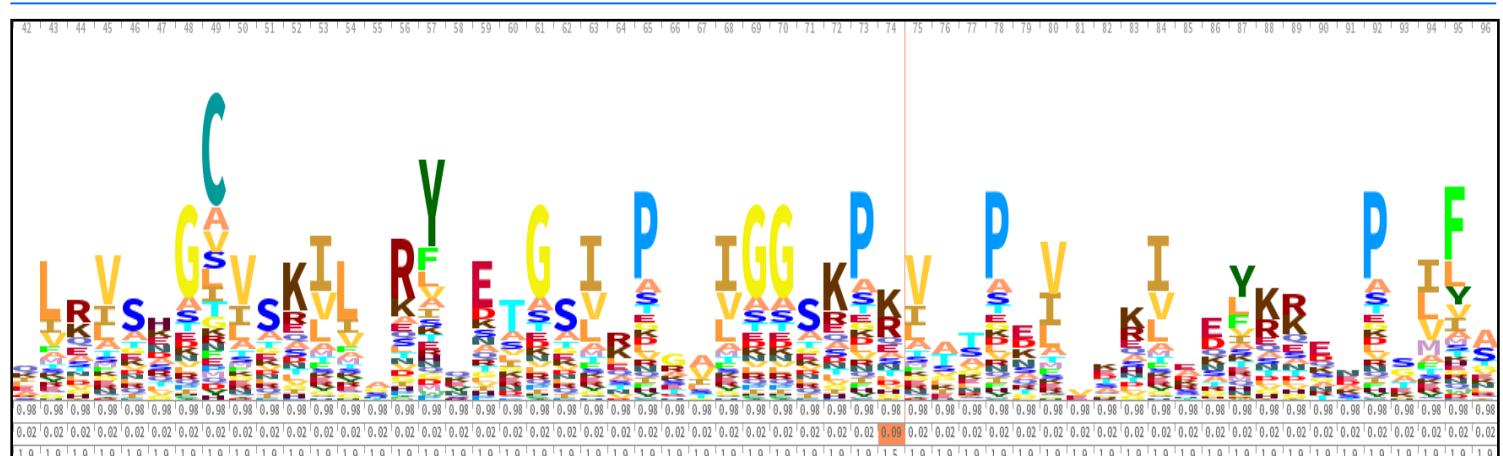


Note down the position in the alignment where all but one seed sequence has a gap.

Note the consensus character at this point and its most logical interpretation.

Back again to the **Pfam PAX** entry page. Click on the **HMM Logo** link on the left of the page. This is a way of visualising the **HMM** profile computed from the seed sequence alignment you have just been viewing. The logos are indubitably very beautiful. There is a link their documentation just above the picture.

How is the heavily gapped position of the seed alignment represented in its **HMM Logo**?



How would you interpret the Logo in this region?

Go back now to the **PAX6_HUMAN** UniProtKB/Swiss-Prot entry. Find the **PRINTS** links in the **Family and domain databases** section (use the y). In **PRINTS**, domains are represented by **fingerprints**. A **fingerprint**, in nserted motifs.

How many links to **PRINTS** would you expect?

What if anything, do you think is missing?

Well, if you thought all was **OK**, you were jolly well wrong! Should be a link to a **Homeobox** domain surely? You will see why it is missing later, when we look at the tools used to search **PRINTS**.

Other databases from the European Bioinformatics Institute (EBI)



26 Full alignment columns that are do not appear in the seed alignment (and so do not contribute to the calculation of the HMM), are shown in lower

Browsing Genomes with Ensembl

The objective now is to examine **PAX6** and related genes in the context of the entire human genome. You will use the genome browser **Ensembl**, one of several well known facilities allowing easy access to genomic information. Similar databases and browsers can be found at **NCBI** and the University of California, Santa Cruz (**UCSC**).

Go to the **Ensembl** home page (www.ensembl.org). Choose to **View full list of all Ensembl species** using the link just under the **Select a species** menu.

Note that **Ensembl** offers far more than just the Human Genome.

In particular, note the links to **EnsemblPlants**, **EnsemblFungi**, **EnsemblBacteria** etc. **Ensembl** databases at the bottom of the list.

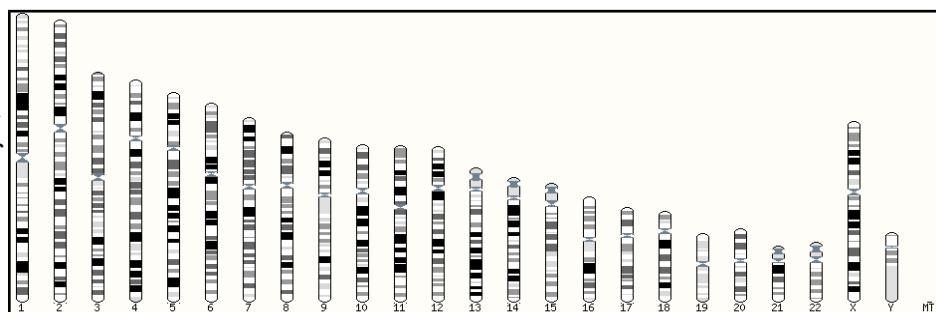
During this exercise, you will only look at the Human genome, by far the most fully developed. However, all the other **Ensembl** genomes are behind the same interface. The techniques required to examine the Human genome are broadly those required to examine any **Ensembl** genome.

Try looking at the **Species tree** by clicking on the **View the full Ensembl species tree** link (at the top of the **Species list** page). This shows the main (i.e. vertebrate) **Ensembl** species arranged according to their probable evolution.



Move back to the **Ensembl** Home page. Click on the Human genome icon.

Select the **View karyotype** link. Your reward will be an image of the banding patterns of all the human chromosomes.



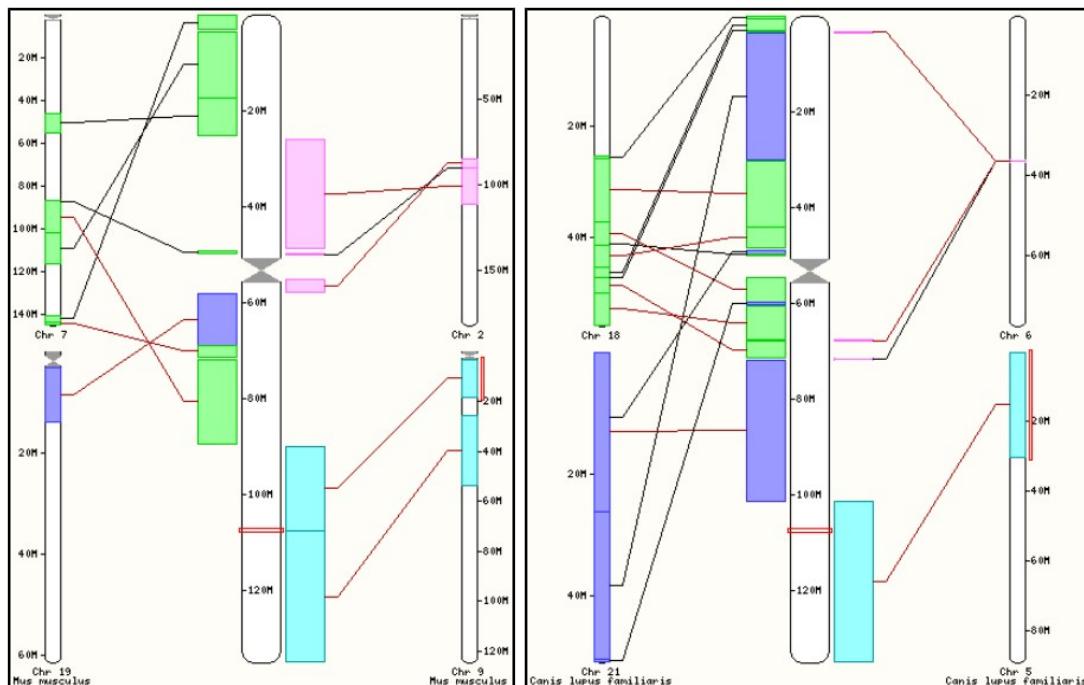
Notice the links to the major alternative genome database browsers, particularly the two very popular options from America. Try one or both of these. You will be linked to a view from the alternative browser as close to the **Ensembl** page you are viewing as is possible. The **NCBI** site, in this instance, offers a very similar view of all the chromosomes. An easy route to these alternative services can be very useful. No one provider is “best” at everything.

From the **Ensembl Karyotype** view, select the **PAX6** chromosome and then **Chromosome Summary** from the menu presented. Look at the **PAX6** chromosome.

Is it a gene dense region? _____

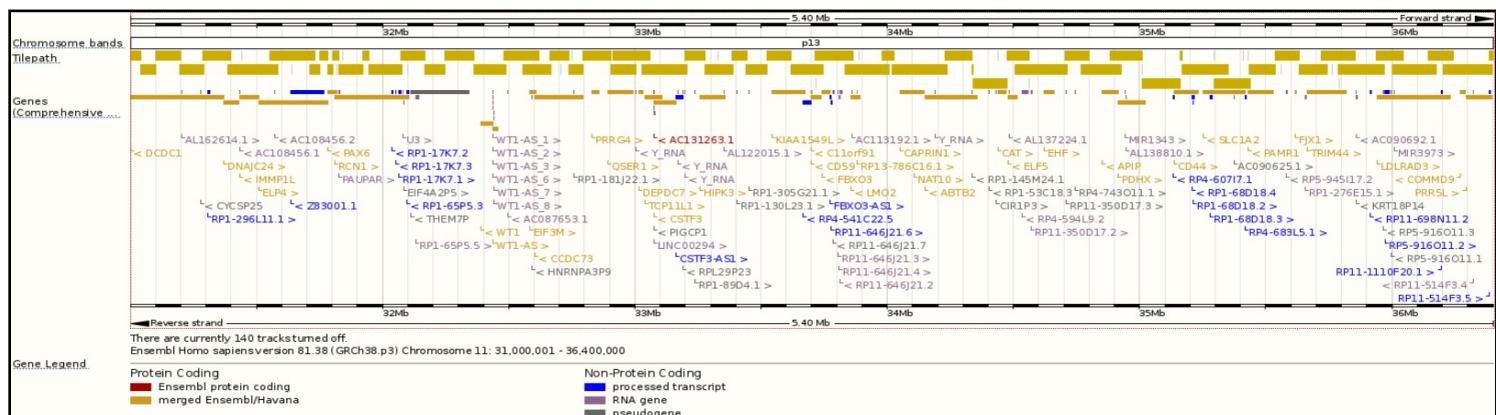


What about Variation density? _____



A short diversion. Click on the **Synteny** link on the left hand side of the page. A graphic will appear showing all regions (over **100,000 bp**) of Human Chromosome 11 that are very similar to regions of the mouse genome. You can choose from a number of other **Ensembl** species. I choose **mouse** and **dog**. Diversion over, move back to the summary of Human Chromosome 11.

Click on your chosen band and select the proffered link to the region. A **Region overview** is generated. Look in the section marked **Genes (Comprehensive ...)** you should be able to locate **PAX6**.



Can you also see the two other genes you might have expected to be in this region? _____

Click on the **PAX6** gene name and select the **Location** link. **Ensembl** zooms into a **Region in detail** view centred around **PAX6**. This view is comprised of two illustrations. The first is an overview showing the location of **PAX6** and immediately neighbouring features, predominantly genes. The colours of the genes represented in this display indicate the gene type (see **Gene Legend**). The second illustration shows a detailed view of the region exactly spanned by **PAX6**²⁷.

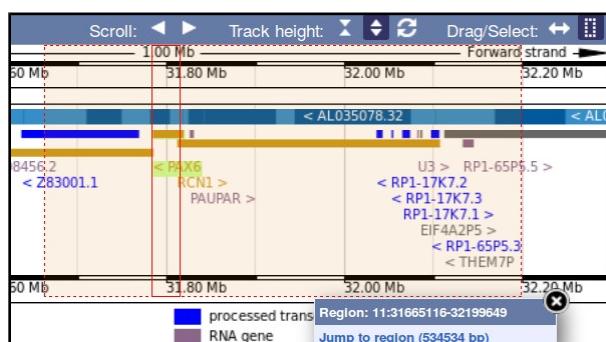


In both views, the thick alternately light and dark blue line represents how a minimal set of **contigs** (simply - sequencing projects) were aligned to construct the chromosome. The red rectangular box in the overview indicates the region of the chromosome represented in the detailed view.

The detailed view **Location** bar indicates the region you are viewing and allows adjustment and zoom. In the detailed view, the forward strand is described above the light/dark blue line, the reverse strand below. **PAX6** is on the reverse strand and so its predicted transcripts appear below the blue line and should be read from right to left. The filled boxes of the transcripts represent coding exons, the unfilled boxes non-coding exons. The wiggly lines joining the boxes are the introns. As should not surprise you, many of the transcripts of **PAX6** span two **contigs**.

There are a number of ways to customize the region displayed in the **Region in detail** view. The most dramatic is to **Scroll:** ← → the image with the red box left or right. The area of focus (governed by the size of the red box) remains constant, but is adjusted horizontally. When you release your mouse, you are asked whether you wish your detailed view to reflect the new logical position of your red box²⁸ (**Update this image**), or whether you wish to bottle out and return from whence you came (**Reset scrollable image**). Try it.

To scroll in a more reserved fashion, select the **Scroll to a region** part of the **Drag/Select: ← →** button. Now you can scroll your view left or right by clicking on the overview image and moving your mouse left and/or right. Once you have done this, **Ensembl** checks that you really like where you ended up in the same way it did for more abandoned scrolling. Try it.



To change the size of the red box defining the area displayed in detail, click on the **Select a region** part of the **Drag/Select: ← →** button. Then drag your mouse over the region you wish to be displayed. When you release the mouse button, you will be asked whether you wish to “**Jump to region**”. Choosing “**Jump to region**” (the alternative being to click on the **X**, which abandons your selection) resizes the region in view to the new size of the red box. Try it.

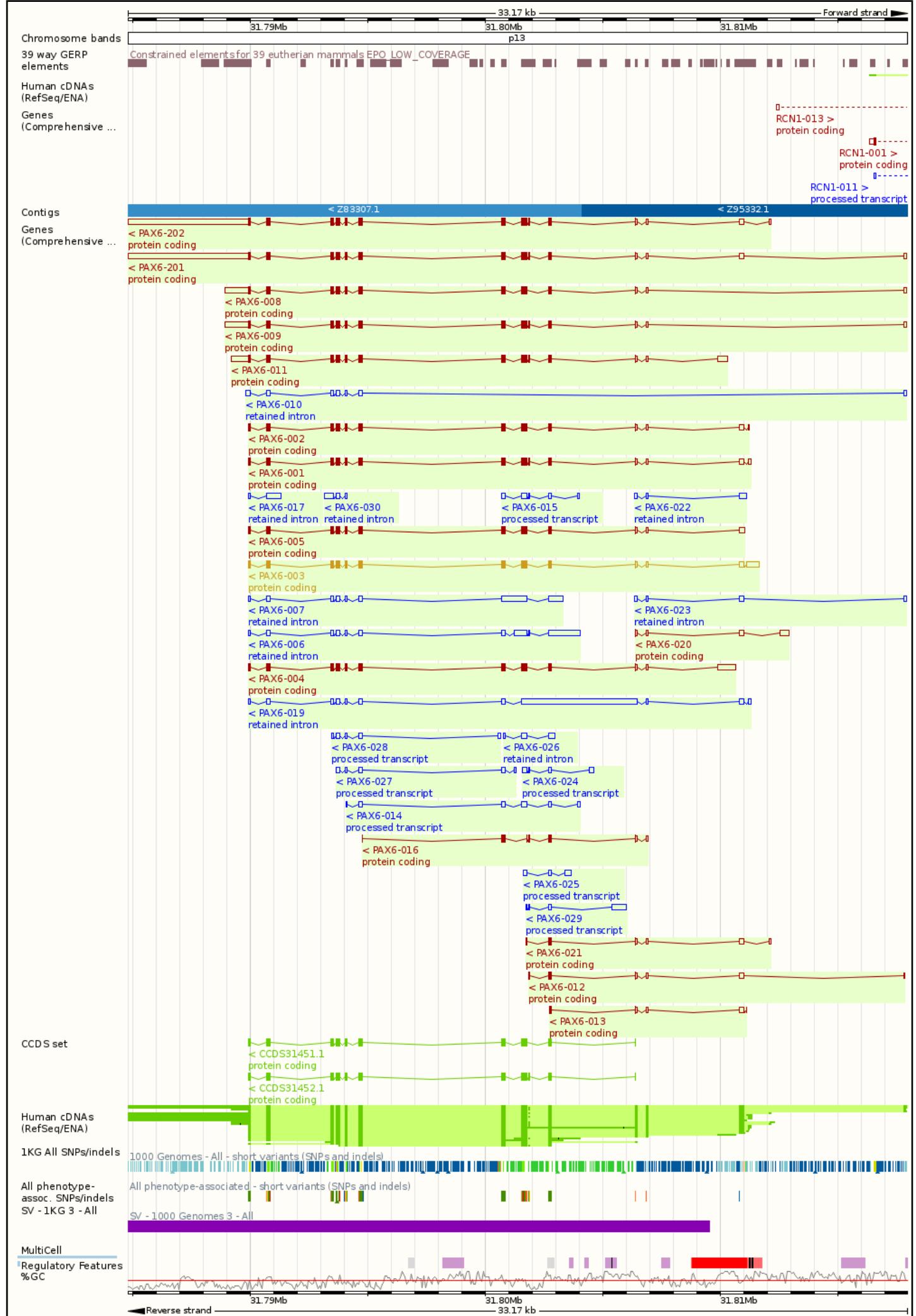
If you just click anywhere in the overview, you will be asked if you wish to “**Centre here**”. If you do this, both views will be re-centred as requested without any adjustment to the size of the region in view. Try it.

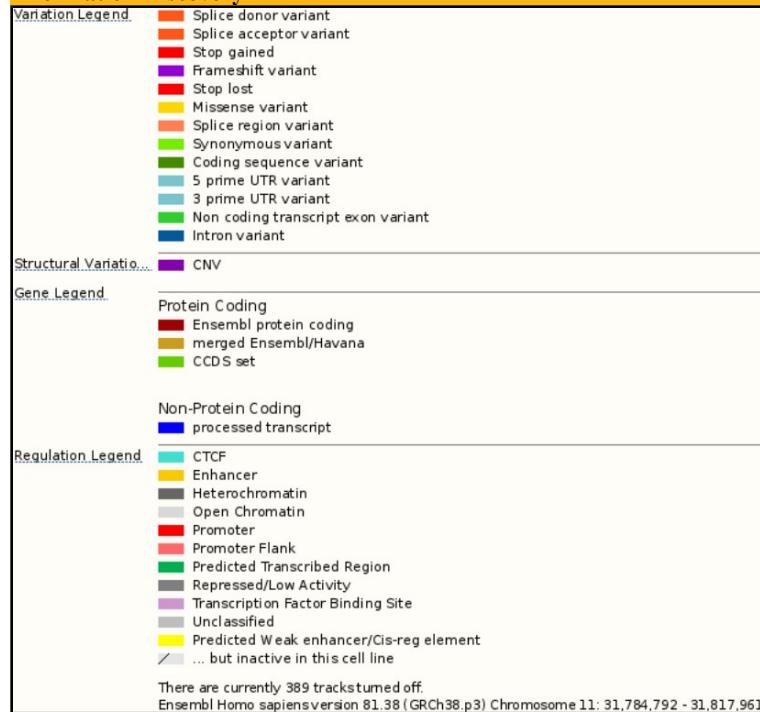
For single base accuracy, you could set the **Location** values in the box provided, but I wonder when one would do this? These possibilities examined, use the **Gene** field of the to get **PAX6** centrally back into focus.

Location:	11:31784792-31817961	Go
Gene:	PAX6	Go

²⁷ The simplest (most sensible?) route to this point would have been to use the search facility offered from the **Ensembl** home page. From here you could have specified **Human** as your organism of choice plus either **PAX6** or **aniridia** as a search term to indicate your area of interest. This would get you a textual view of the correct gene (**PAX6**). From here, it is a simple matter to jump to the **Region in detail** view that now enlivens your life. Faster and more direct? True ... but where is the poetry? Try it, if you have the time and inclination.

²⁸ That is, the centre of the display, the red box actually moves with the display.



Information Discovery

In the default view, transcripts confidently predicted by the **Ensembl** pipeline and/or the **Vega/Havana** project are shown. The colour of a transcript indicates its type²⁹.

The **Human cDNAs (RefSeq/ENA)** and **CCDS set**³⁰ tracks show the prime evidence for the transcript predictions.

The **Human cDNAs (RefSeq/ENA)** track represents very close matches between good quality human **cDNA/mRNA** sequences and the genome. Dark green boxes indicate matched regions and suggest the position of all exons. Light green boxes indicate regions of the genome between matches, suggesting introns.

The **CCDS set** track represents very close matches between the most assured coding DNA sequences and the genome. Dark green boxes indicate matched regions and suggest the position of coding exons. Wiggly lines join **CCDS** matches, suggesting the positions of introns between coding exons.

A good match between a high quality **cDNA/mRNA** sequence and the genome can suggest all the exons of a transcript. A corresponding good match between a **CCDS** sequence and the genome can suggest which of that transcript's exons code for protein.

What are the (familiar?) contig numbers containing all of **PAX6**?

Explain the visible differences between the coding exons of transcripts **PAX6-008** and **PAX6-009**?

From the left hand side of the browser page, select **Configure this page**. Turn on the features:

Genscan predictions (from **Genes and transcripts** → **Prediction transcripts**, choose **with labels**)

Proteins (mammal) from **UniProt** (from **mRNA and protein alignments** → **Protein alignments**, choose **Normal**)

Then click on **SAVE and close** (the in the top right hand corner). The **Detailed view** will reassemble showing where any **Mammalian Uniprot proteins** match, extremely closely, translated regions of the genomic sequence. As do the **CCDS set** track, these matches indicate where protein coding exons exist in the genome.

The **Genscan prediction** track shows where a program called **Genscan** predicts gene structures directly from the genomic sequence. **Genscan** bases its judgement on models derived from other known human gene structures. **Genscan** is very good, but it does get over excited at times. It misses little, but tends to predict some spurious exons³¹. **Genscan** and similar programs will be discussed briefly later (in a **Supplementary Exercise**).

What **PAX6** exon of note has **Genscan** omitted to predict?

Select **Configure this page** once again. Turn on the features:

Vega Havana (from **Genes and transcripts** → **Genes**, choose **Expanded with labels**)

EST-based (from **Genes and transcripts** → **Genes**, choose **Expanded with labels**)

29 See the **Gene Legend** at the bottom of the display, and illustrated here.

30 **CCDS (Consensus CoDing Sequence)** is a collaborative effort to identify a core set of human and mouse protein coding regions that are consistently annotated and of high quality. The long term goal is to support convergence towards a standard set of gene annotations.

31 Particularly as it is run in the **Ensembl** pipeline. Here its purpose is only to identify where genes are likely to be. Sequence comparison between just these regions and coding sequences (**CCDS** sequences, proteins, cDNAs etc.) are then used to predict transcript detail. **Ensembl** only requires **Genscan** to work approximately to reduce the volume of sequence comparisons rather than to generate “stand alone” gene predictions.

Then click on **SAVE and close**. You should now have in view three types of transcript prediction including purple **EST-based genes** that are suggested only by matches with **Expressed Sequence Tags (ESTs³²)**. Of course, the **Vega Havana** transcript predictions are a subset of the predictions displayed originally by default.

³² An Expressed Sequence Tags (**EST**) is a short (**200-500** nucleotide) sequence representing a single reads of a cDNA. As it is generated from a single sequencing read, it will not usually be of very high quality.

For pedants only. Can you see how to identify the **Havana** predictions from the **Ensembl** predictions by the way they are numbered? _____

The features now displayed represent just a few of those offered by **Ensembl**³³. Feel free to try more.

Before looking at some of the **gene** and **transcript** properties **Ensembl** offers, it would be good to save the genomic sequence of this region for analysis later on.

To effect this, first click on the  **Export data** link on the left hand side of the page.

PAX6 is on the negative strand of the genomic region in view, so in the **Select location** section of the **Export data** page the will fly forth, you must change the strand selection from  to .

Ask for **500** base pairs of extra sequence at either end of the **PAX6** gene. That is, set both **5' Flanking sequence (upstream)**: to **500**.

Location to export:	chromosome:GRCh38:11:31784792:31817961:1
Output:	FASTA sequence
Select location:	11 * 31784792 * 31817961 * -1
5' Flanking sequence (upstream):	500 * (Maximum of 1000000)
3' Flanking sequence (downstream):	500 * (Maximum of 1000000)

Click on the **Next >** button.

Please choose the output format for your export

- [HTML](#)
- [Text](#)
- [Compressed text \(.gz\)](#)

Choose **Text** as the **output format** for the sequence to be saved.

```
>11 dna:chromosome chromosome:GRCh38:11:31784292:31818461:-1
GGCCAGTTGAGGGTACTCATCGAGCCTCGAACCTCTCTAAATGATTCTGCCTGCAAAA
GGCCTCTCCATCCGGCGGCCGCGCTTCGGGTCTCTCGATGAAGGGACTCTCTGGGAT
CGGAGGGGGACAGGGTGATTACCAAGAGGGTAGCTGGCCAGCTAAAGGGAGAGATC
TTGGGCCCTAGTGCGCAAGGGTGGAGGCGCAGCTGGCAAGACTAGTTCTGGGG
ATCGACTTACGCCATACAGGACGGGCCAGGGCTGGACGGCCGGGCTAGAGCAGTC
ACAGGCCGGCCAAGGAAGGCAAGGCAAGGGTTGGAGGCCGGCCGGCTGGGG
GAAGCAGGCTCCGGCCGGCCGGAAACTAGTCGGCCAGAGCTGTGCCAACCTAGCC
GCCATGAGCTCACGGGGGGGGGAGCAATGAGGAGGGCTGGCTGGATTTAAGGA
AAGTAGCGCTCTGAGCACCTCTTATCATCGACATTCAACTCTGGGAG
GTCTCGCGTAGAACCGCGCTGCAAGCTGCACTTCCCCTGCGAGCGGGTGAAGA
GTGTTGGAAACCCGGCTGCAAGGCTAACCTGCTCCCGCCCTCGCTCCAGGTAACCG
CCCCGGCTCGGCCCCGGGGCTCGGGGCCGGGCTCTCCGCTGCCAGGACTG
CTGCCCCAACATAAGCCGGCCCAAGTGGCCGGGGCTTGATTTCCTTTAAAG
GAGGCATACAAGATGGAAGGGAGTTACTGAGGGAGGGATAGGAAGGGGGTGGAGGG
GACTTGTCTTGGCGAGTGTGCTTCTGCAAAGATGCAAATGTTTCACTCTTAAGAG
TGGACTTCCAGTCGGCCCTGAGCTGGAGTAGGGGGGGAGGCTGCTGCTGCTG
CTAAAGGCACTCGGACCGGAAAAATGCAAGGAAGGTGGGGAGGCACTTGCATCCAGACC
TCCCTGCACTCGCAGTTACGACATCCACGCTGGCTGGGGAAAGTCCGTACCCGGCTGGAGC
GCTTAAAGCACCCCTGGCGGGCTGGGGAGGTTGAGGAGCTGGCTGGAGGCT
AGTGAGATGGCTGGACCGAACAAAGCTAGAGATGGGGTTCTGTTCTAGAAAGACGC
GGAGTACGAAAGAATGCGGGCGACAGAGCTGGCAGCGCTGAAGCTCCAGCTGTGAT
TTGAGCTTCACTCGGAAGACCTATAATTAGCGATTCTACTGAGCTAGAACCGGGCT
CCGGTTACTGCGGGCGCTCGCCTGGCTGCGCTGGGGAGCGCGCGGGCCATGGAG
```

In your browser you should now have the genomic region of the **PAX6** gene, with **500** base pairs of flanking sequence on either end, in **FASTA** format.

Do whatever it takes to download this to a file called:

pax6_genomic.fasta

on your **Desktop**. Then use a suitable text editor to change the rather clumsy first line to:

>pax6-genomic sequence

³³ My display is telling me that I have “currently nearly 400 tracks turned off”!

Move back to the **Ensembl** view of the **PAX6** genomic region.

Click on a gold **Ensembl/Havana gene** **Ensembl** transcripts in the **Detailed view** and then on the link to the **Gene**³⁴.

You now see the **Gene summary** for **PAX6**³⁵. Click on the **Show transcript table** button to display the transcript information textually. Transcripts are not necessarily in the same order in the table as in the diagram.

Name	Transcript ID	bp	Protein	Biotype	CCDS	UniProt	RefSeq	Flags
PAX6-201	ENST00000419022	6922	436aa	Protein coding	CCDS31452	F1T0F8 P26367	NM_001258462 NP_001245391	TSL:1 Gencode basic APPRIS P4
PAX6-202	ENST00000606377	6860	436aa	Protein coding	CCDS31452	F1T0F8 P26367	NM_001258463 NP_001245392	TSL:1 Gencode basic APPRIS P4
PAX6-009	ENST00000379129	2616	436aa	Protein coding	CCDS31452	F1T0F8 P26367	-	TSL:5 Gencode basic APPRIS P4
PAX6-011	ENST00000379107	2591	436aa	Protein coding	CCDS31452	F1T0F8 P26367	-	TSL:5 Gencode basic APPRIS P4
PAX6-008	ENST00000379132	2574	422aa	Protein coding	CCDS31451	P26367 Q66SS1	NM_001127612 NP_001121084	TSL:5 Gencode basic APPRIS ALT1
PAX6-003	ENST00000379123	2160	422aa	Protein coding	CCDS31451	P26367 Q66SS1	NM_000280 NM_001258464 NP_000271 NP_001245393	TSL:1 Gencode basic APPRIS ALT1
PAX6-001	ENST00000379115	1763	436aa	Protein coding	CCDS31452	F1T0F8 P26367	NM_001604 NP_001595	TSL:1 Gencode basic APPRIS P4
PAX6-002	ENST00000241001	1631	422aa	Protein coding	CCDS31451	P26367 Q66SS1	-	TSL:1 Gencode basic APPRIS ALT1
PAX6-005	ENST00000379111	1627	422aa	Protein coding	CCDS31451	P26367 Q66SS1	NM_001258465 NP_001245394	TSL:1 Gencode basic APPRIS ALT1
PAX6-004	ENST00000379109	2157	422aa	Protein coding	-	P26367 Q66SS1	-	CDS 3' incomplete TSL:2
PAX6-020	ENST00000525535	677	2aa	Protein coding	-	-	-	CDS 3' incomplete TSL:3
PAX6-021	ENST00000524853	574	58aa	Protein coding	-	E9PKM0	-	CDS 3' incomplete TSL:4
PAX6-012	ENST00000423822	567	62aa	Protein coding	-	B1B1I9	-	CDS 3' incomplete TSL:3
PAX6-016	ENST00000455099	497	124aa	Protein coding	-	B1B1J0	-	CDS 3' incomplete TSL:5
PAX6-013	ENST00000438681	455	39aa	Protein coding	-	B1B1I8	-	CDS 3' incomplete TSL:2
PAX6-029	ENST00000533156	847	No protein	Processed transcript	-	-	-	TSL:5
PAX6-014	ENST00000471303	782	No protein	Processed transcript	-	-	-	TSL:5
PAX6-027	ENST00000531910	643	No protein	Processed transcript	-	-	-	TSL:3
PAX6-015	ENST00000481563	613	No protein	Processed transcript	-	-	-	TSL:3
PAX6-028	ENST00000530373	572	No protein	Processed transcript	-	-	-	TSL:4
PAX6-025	ENST00000530714	567	No protein	Processed transcript	-	-	-	TSL:4
PAX6-024	ENST00000534353	540	No protein	Processed transcript	-	-	-	TSL:4
PAX6-019	ENST00000533333	6173	No protein	Retained intron	-	-	-	TSL:2
PAX6-006	ENST00000470027	2842	No protein	Retained intron	-	-	-	TSL:2
PAX6-007	ENST00000494377	2460	No protein	Retained intron	-	-	-	TSL:2
PAX6-010	ENST00000464174	979	No protein	Retained intron	-	-	-	TSL:5
PAX6-017	ENST00000474783	702	No protein	Retained intron	-	-	-	TSL:2
PAX6-030	ENST00000532916	627	No protein	Retained intron	-	-	-	TSL:3
PAX6-026	ENST00000534390	578	No protein	Retained intron	-	-	-	TSL:4
PAX6-023	ENST00000532175	524	No protein	Retained intron	-	-	-	TSL:3
PAX6-022	ENST00000527769	487	No protein	Retained intron	-	-	-	TSL:3

Note the number of **RefSeq mRNAs** and **RefSeq proteins** associated with **Ensembl** transcripts predictions.

Which of the **20 RefSeq mRNAs** reported by **GeneCards** can be seen here?

Why would you suppose these **mRNAs** were selected and the others ignored?

34 It does not really matter which transcript you choose. All the **PAX6** transcripts correspond to the same gene. However your choice will affect some of the results that follow. This is not a problem at the time of typing ... there is only one gold transcript to choose from!

35 Or you might have taken the more pedestrian route of clicking on the **Gene: PAX6** tab waiting patiently at the top of the page?

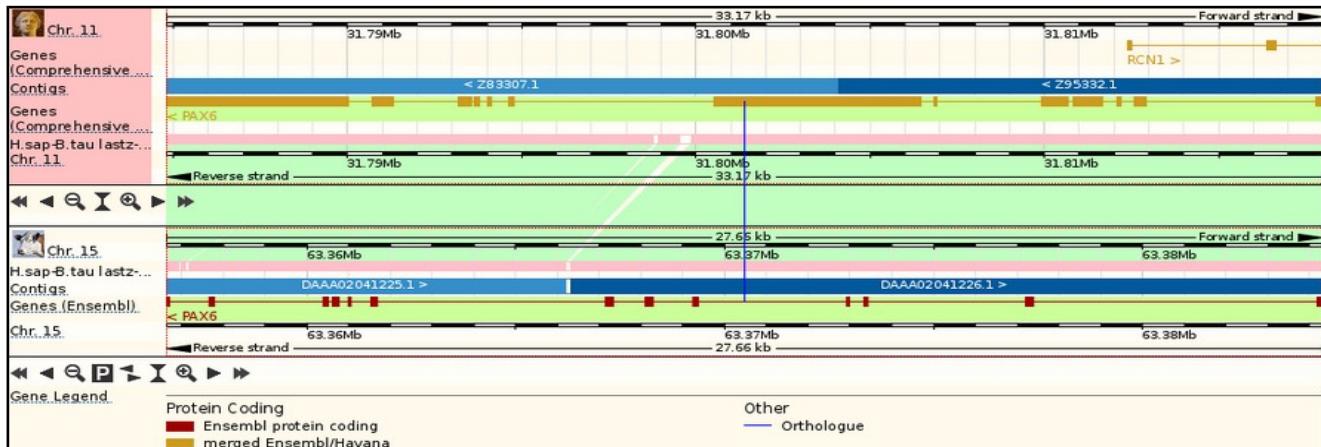
Click on the **Othologues** link in the left hand side of your browser page. Take a look at some of the alignments providing support for the homologous relations. The protein alignments are the more informative.

Using the evidence of the protein alignments, which **PAX6** isoforms do the fruitfly orthologues most resemble? _____

Move back to the othologue list and try one or more of the **Region Comparison** links. I selected the one for **Cow**. Not too far and not too near I mused? In the regional comparison, you can still see familiar neighbouring genes such as **ELP4** and **RNC1**. Not so sure I wish to be quite this similar to a cow?



In the more detailed comparison, the similarities are even more worryingly apparent!



Once your curiosity is completely sated, move back to the othologue list.

Click on the **Paralogues** link. Paralogues here should match those reported by GeneCards as GeneCards obtains its **Paralogues** report from Ensembl.

Do the **Parologue** reports of GeneCards and Ensembl agree? _____

Try some **Alignment(protein)** links to view an alignments between a **PAX6** isoform and the selected **paralogues**. The best strategy might be to use the **View sequence alignments of all paralogues** link.

Which isoform of **PAX6** has been chosen for the alignments, and why would you suppose it was selected? _____

Which isoform is most common amongst the **paralogues**? _____

Move back to the **list of paralogues**. Try one or more of the **Region Comparison** links. Not nearly so interesting as for the orthologues as the only expectation of similar regions here would be the two gene **paralogues**.

Move back to the list of **paralogues**. Go to the **Gene tree** representing proteins potentially related to **PAX6**. This picture gets more outrageously huge each time I look at it! I will trust you get to see it for yourselves. If not, click here. Or, if you are off line, [here](#).

To expand any subtree, click on the horizontal triangles of your choice and select **expand this sub-tree**. To expand the entire tree, click on any of the horizontal triangles , stand well back and select **expand all sub-trees**.

You can download this tree in various textual forms using the  button from the menu at the top of the graphic. **Newick** format, accepted by most tree drawing programs, is probably the most important of the many offered.

Click on the **Supporting evidence** link in the left hand side of your browser page.

Transcript	CDS support	UTR support	Other transcript support	Exon supporting features
ENST00000241001 [view evidence] [align] CCDS31451.1				35
ENST00000379107 [view evidence] [align] CCDS31452.1				35
ENST00000379109 [view evidence]				35
ENST00000379111 [view evidence] [align] CCDS31451.1				35
ENST00000379115 [view evidence] [align] CCDS31452.1				35
ENST00000379123 [view evidence] [align] CCDS31451.1			[align] NM_000280.4	34
ENST00000379129 [view evidence] [align] CCDS31452.1				37
ENST00000379132 [view evidence] [align] CCDS31451.1				37
ENST00000419022 [view evidence] [align] CCDS31452.1		[align] NM_001258462.1		34
ENST00000423822 [view evidence]				30
ENST00000438681 [view evidence]				21
ENST00000455099 [view evidence]				26
ENST00000464174 [view evidence]				8
ENST00000470027 [view evidence]				12
ENST00000471303 [view evidence]				13
ENST00000474783 [view evidence]				2
ENST00000481563 [view evidence]				8
ENST00000494377 [view evidence]				8
ENST00000524853 [view evidence]				30
ENST00000525535 [view evidence]				21
ENST00000527769 [view evidence]				13
ENST00000530373 [view evidence]				8
ENST00000530714 [view evidence]				6
ENST00000531910 [view evidence]				8
ENST00000532175 [view evidence]				21
ENST00000532916 [view evidence]				6
ENST00000533156 [view evidence]				8
ENST00000533333 [view evidence]				29
ENST00000534353 [view evidence]				7
ENST00000534390 [view evidence]				4
ENST00000606377 [view evidence] [align] CCDS31452.1		[align] NM_001258463.1		34

For each transcript **Ensembl** offers evidence to support the existence of the **CDS**³⁶, **UTRs**³⁷ and **Exons**³⁸. Take a look at some of the **[align]ments** and sequences³⁹ providing the support for the **CDSs** and **UTRs**.

Click on the **view evidence** link to view the support for **ENST00000419022**. In the **Transcript supporting evidence** section, sequence matches supporting the entire transcript are recorded. Here there is match with a **RefSeq**

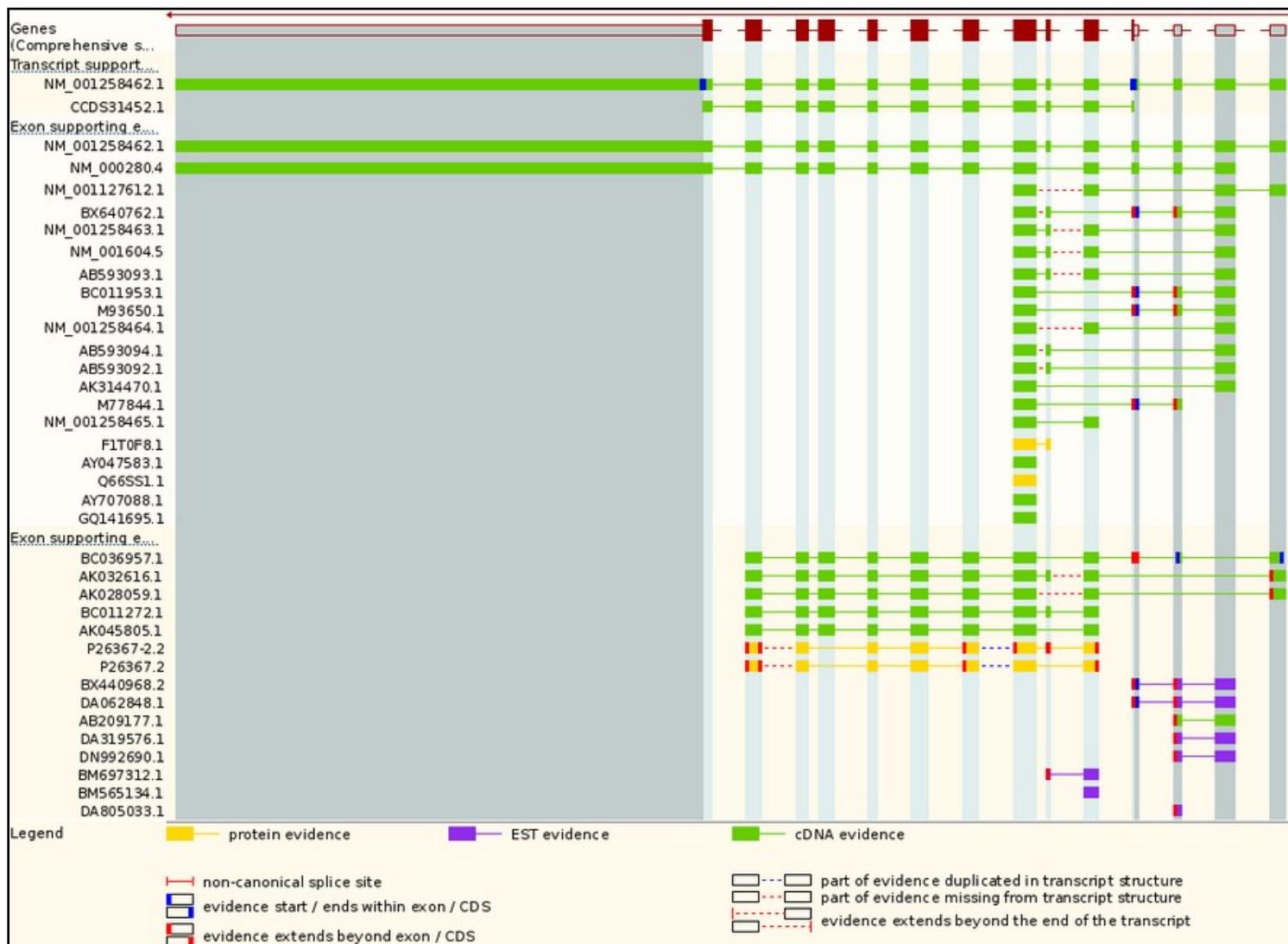
36 CoDing Sequence, typically a match with a protein sequence and/or a CCDS entry.

37 UnTranslated Regions, typically matches with mRNA sequences.

38 Matches with protein and/or coding DNA sequences.

39 Those starting NP_ are Refseq proteins. Those starting NM_ are Refseq mRNA sequences. RefSeq links will take you to the NCBI.

mRNA supporting all exons of the transcript⁴⁰ and CCDS and protein matches suggesting which exons are coding. In the **Exon evidence** section, extra matches supporting individual exons of the transcript are illustrated.



Some matching sequences offer no support for the 6th exon from the right. Why do you suppose this is? _____

Why is there no protein or CCDS evidence for exons 1, 2 and 3? _____

Until recently (mid-2014), the **RefSeq mRNA** match in the **Transcript evidence** section did not match all exons. Was this logical? _____

⁴⁰ This need not necessarily be the case. In fact, until recently (mid-2014) this transcript was supported by a **RefSeq mRNA** that had the **6th** exon missing! Essentially, **Ensembl** does not take the **RefSeq** mRNAs as defining a transcript by themselves. This is reasonable as these mRNA sequences do not necessarily represent a single carefully sequenced mRNA. **RefSeq** mRNAs are typically constructed from many imperfect sequences assumed to be of the same cDNA/mRNA and cannot therefore be assumed to be always **100%** accurate. Oh that life was just a little more straight forward?

Click the **Exons** link (from Transcript-based displays → Sequence). Exons, Introns and Variations within Exons are clearly displayed⁴¹.

Intron 3-4	31,806,848	31,806,463	386	gcaagttctgtggggctgtttgg.....ttaactcttatattttttgtctaacag		
ENSE00002523992	31,806,462	31,806,402	-	AGCCCCATATTC <ins>G</ins> AGCCCCGTGGAAT <ins>CC</ins> CGCGCCCCA <ins>C</ins> CCAGAGCCAGC <ins>AT</ins> GCAGAAC A		
Intron 4-5	31,806,401	31,802,835	3,567	gtaagtgcctctggctttctggaa.....tttcctctctccctttctcag		
ENSE00003602163	31,802,834	31,802,704	1	0	131	GTCACAGC <ins>G</ins> GAGTGAAT <ins>C</ins> AGCT <ins>CG</ins> TGGT <ins>T</ins> CTT <ins>T</ins> CTCA <ins>A</ins> CCGGC <ins>G</ins> GCCACTGCC <ins>G</ins> CACT CC <ins>A</ins> CCGGCAGAAAGATTGTAGAGCTA <ins>C</ins> CTCACAGC <ins>G</ins> G <ins>G</ins> CC <ins>C</ins> GGCGTGC <ins>G</ins> ACAT <ins>T</ins> TCC <ins>G</ins> GA <ins>T</ins> TCTG <ins>C</ins> AG
Intron 5-6	31,802,703	31,801,913	791	gtgatcctccggggccccact.....ttgaaggatattttgttgtatag		
ENSE00003512677	31,801,912	31,801,871	0	0	42	ACCCATGCAGATGCAAAC <ins>I</ins> CCAAGTGCTGG <ins>A</ins> CAATC <ins>A</ins> AAAC
Intron 6-7	31,801,870	31,801,777	94	gtaagttgtcatgtttaatgcat.....tttctgtccacttcccatacg		
ENSE00003523920	31,801,776	31,801,561	0	0	216	GTG <ins>C</ins> CAAC <ins>C</ins> CGATGTGTEAGTA <ins>AA</ins> AT <ins>T</ins> CTGGG <ins>C</ins> AGGTATT <ins>A</ins> AGAGACT <ins>G</ins> CC <ins>T</ins> CC <ins>C</ins> AT <ins>G</ins> CCCAGGGCAAT <ins>C</ins> GGTGGT <ins>A</ins> TGAAACC <ins>G</ins> AGAGTAG <ins>C</ins> ACT <ins>C</ins> CA <ins>A</ins> AGTTGT <ins>A</ins> AGC <ins>A</ins> AA <ins>A</ins> GCC <ins>C</ins> AGTA <ins>T</ins> AAGCGG <ins>E</ins> AGT <ins>CC</ins> GT <ins>C</ins> CA <ins>T</ins> CTT <ins>G</ins> CT <ins>G</ins> GA <ins>A</ins> ATC <ins>C</ins> GAGACAGAT <ins>T</ins> ACT <ins>G</ins> TCC <ins>G</ins> AC <ins>G</ins> GG <ins>G</ins> TGTACCAACG <ins>A</ins> TA <ins>A</ins> ATAC <ins>C</ins> AA <ins>G</ins>

How many exons are there in this transcript? _____

What are the first two bases and what are the last two bases of nearly every intron? _____

How long is the sixth exon and why would this concur with your expectations? _____

Explain the **Start Phase** and **End Phase** columns? _____

Click on the **cDNA** link (from Transcript-based displays → Sequence). The default view of the transcript cDNA is ornate, exhibiting all the features described in the Key.

R Y R ***
421 CCCATATTCGAGCCCCGTGGAATCCCGCGCCCCACCCAGAGCCAGCATGCAGAACAG
.....ATGCAGAACAG
.....-M-Q-N-S

* * * *** * * * ***K K ** *
481 TCACAGCGGAGTGAATCAGCTCGTGGTTCTTTCTCAACCGGCGGCCACTGCCGCACTC
12 TCACAGCGGAGTGAATCAGCTCGGTGGTCTTTGTCACAGGGCGCCACTGCCGGACTC
4 --H-S-G-V-N-Q-L-G-G-V-F-V-N-G-R-P-L-P-D-S

** S *** * * Y * * * * Y ***WM*** *Y*Y*
541 CACCGGCAGAAAGATTGAGAGCTACTCACAGCGGGCCCGGCGTGCGACAATTCCC
72 CACCCGGCAGAAAGATTGTAGAGCTAGCTCACAGCGGGGCCGCGCGTGCGACATTCCCG
24 --T-R-Q-K-I-V-E-L-A-H-S-G-A-R-P-C-D-I-S-R

* S * ** W R * * * *
601 ATTTGCAACCCATGCAGATGCAAACICCAAGTGCTGGACAATCAAAACGTGTCAA
132 AATTCTGCAGACCCATGCAGATGCAAAGTCCAAGTGCTGGACAATCAAAACGTTCAA
44 --I-L-Q-T-H-A-D-A-K-V-Q-V-L-D-N-Q-N-V-S-N

* * * * * * * * * * * * * * * * * * * R Y
661 CGGATGTTAGAATTTGGGCAGGTATTAGGAGACTGGCTCCATCAGACCCAGGGC
192 CGGATGTGTAGTAAATTCTGGGAGGTTAACGAGACTGGCTCATCAGACCCCAGGGC
64 --G-C-V-S-K-I-L-G-R-Y-Y-E-T-G-S-I-R-P-R-A

Somatic mutation: COSM3809082

| | | | | | | | |
|------------|--------------------|--------------------|-----------------|------------|----------|---------------|-------------|
| Codons | Alternating codons | Alternating codons | | | | | |
| Exons | Alternating exons | Alternating exons | | | | | |
| Variations | 3 prime UTR | 5 prime UTR | Coding sequence | Frameshift | Missense | Splice region | Stop gained |
| | Synonymous | | | | | | |
| Other | UTR | | | | | | |

Click on the **Protein** link (from Transcript-based displays → Sequence). Add the variation information to the default view by clicking on the **Configure this page** link and ticking **Show variants**. Click on **Save and close**. A number of features, including sequence variations, are shown (details in the Key). By clicking on variations, further information can be obtained, try a few.

Exons Alternating exons Alternating exons Residue overlap splice site
Variations Coding sequence Frameshift Missense Splice region Stop gained Synonymous
Somatic mutation: COSM3809082
Position 11:31794105
Alleles C/A
Amino acids R/I
Codons aGa/ta
Consequences Missense variant
Explore this variant
Gene/Transcript Locations
Phenotype Data

MQNSHSGVNQLGGFVFNGRPLDSTRKIVELAHASGARPDISRLITHADAKVQLDNQ
NTSNCVSKILGRYETGSIRPRAIEGSKPRVATPBVVSHADYKRCPSIFANEFDLR
LSEGVCTDNIPSSSINRVLNABEKQMGADGMYDKIRLMNGODSGWTRPGWEGTI
SVPGOPTDGCQOQEGGGENTNSISSNEDSDEAMPILKRKIRNETSFTOEQIALER
KEFERTHYDFVVAFERLAKIDLPEARIVWENSRAKRFEEERNRROASNTESHIPI
ISSFSTSVYOPIOPTVSSFTSSMIGRTDTALTNTVSALPPMFTMANNLMPOPI
VPSQTSSYCMLPSPEVGRSIDTVPPHMOHTINSQVGTSGTTLIPGVSVPVQV
VESEPDMSQYWPHIO

Many of the variations come from the **HGMD_MUTATION** database. Details of these mutations are not shown. They are only revealed to people who pay for the database. Here, they just make a mess of what would otherwise be a useful display.

Variation: CM003465
Position 11:31801565
Alleles HGMD_MUTAT...
Consequences Coding sequence variant
Explore this variation
Gene/Transcript Locations
Phenotype Data

41 Which variants are displayed can be customised using the **Configure this page** facility, try it if you have time. The types of variation can be determined from the **Key**, a version of which is illustrated above.

Click again on the **Configure this page** link and choose **Select/deselect all (keep clicking it until all selections are unticked)**. Click on **Save and close**. Now the view is set for copying and pasting from the browser window and viewing the sequence clearly.

Where is the start and end of the **Prosite Paired Box** pattern (**R-P-C-x(11)-C-V-S**)? _____

Where, in relation to the pattern, are the extra **isoform 5a** amino acids? _____

Why might the positions of these two features be significant? _____

Click on the **GO graph** link (from **Transcript-based displays → Ontology**). You are offered a very intuitive (if very large) diagrammatic view of the ontology for this transcript.

Give an example of the most specific terms represented? _____

Give an example of the most general terms? _____

For a less poetic view of roughly the same information, click on the **GO table** link (from **Transcript-based displays → Ontology**). Follow one or two of the **GO** links which will take to the relevant **GO** entries from the **Gene Ontology Home** site.

View the **GO** terms of several of the **PAX6** transcripts by clicking on their **Transcript Ids**. End back at **ENST00000419022** (use the **Transcript: PAX6-201** tab at the top of the page if necessary), where you started. Generally, **GO** terms are more prolific here than in **Uniprot**⁴² but the message is the same concerning the domains and functions of the **PAX6** gene transcripts.

Click on the **Domains & features** link (from **Transcript-based displays → Protein Information**). Look at the domains of **Domain type Smart**⁴³. There are two. Predictably, a **Paired box** and a **Homeobox** domain.

| Domain type | Start | End | Description | Accession | InterPro |
|------------------|-------|-----|------------------|--------------------------|--|
| Prosite_profiles | 222 | 282 | Homeobox_dom | PS50071 | IPR001356 [Display all genes with this domain] |
| Smart | 224 | 286 | Homeobox_dom | SM00389 | IPR001356 [Display all genes with this domain] |
| Pfam | 226 | 281 | Homeobox_dom | PF00046 | IPR001356 [Display all genes with this domain] |
| Superfamily | 5 | 144 | Homeodomain-like | SSF46689 | IPR009057 [Display all genes with this domain] |
| Superfamily | 198 | 284 | Homeodomain-like | SSF46689 | IPR009057 [Display all genes with this domain] |
| Pfam | 4 | 142 | Paired_dom | PF00292 | IPR001523 [Display all genes with this domain] |
| Smart | 4 | 142 | Paired_dom | SM00351 | IPR001523 [Display all genes with this domain] |
| Prosite_profiles | 4 | 144 | Paired_dom | PS51057 | IPR001523 [Display all genes with this domain] |
| Prints | 8 | 23 | Paired_dom | PR00027 | IPR001523 [Display all genes with this domain] |
| Prints | 26 | 44 | Paired_dom | PR00027 | IPR001523 [Display all genes with this domain] |
| Prints | 60 | 77 | Paired_dom | PR00027 | IPR001523 [Display all genes with this domain] |
| Prints | 78 | 95 | Paired_dom | PR00027 | IPR001523 [Display all genes with this domain] |

Where do each of the **SMART** domains start and end? _____

Do the regions match your earlier recording? If not, why not? _____

What are the **Interpro**⁴⁴ database identifiers for the two major **PAX6** domains? _____

Why does **Prints** appear to predict four **Paired_doms**? _____

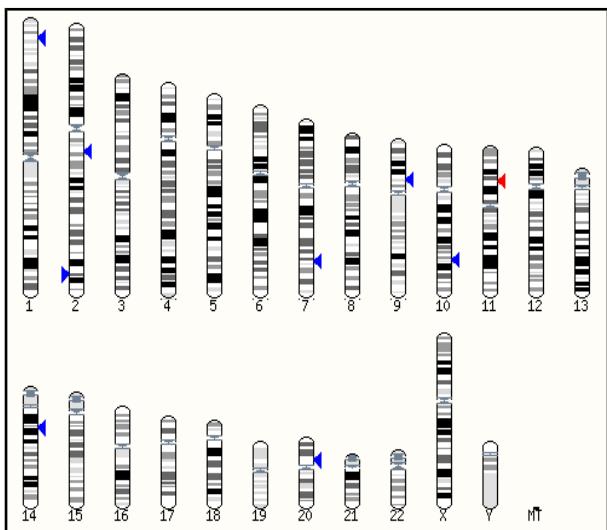
42 Because, as stated at the top of the section, **Ensembl** searches for **GO** terms in both **Uniprot** and **Refseq**. If you were to investigate further you would find the **GO** terms list was not identical for all transcripts (as the protein product is not always the same).

43 **SMART** (a Simple Modular Architecture Research Tool) allows the identification and annotation of genetically mobile domains and the analysis of domain architectures. More than 500 domain families found in signalling, extracellular and chromatin-associated proteins are detectable. These domains are extensively annotated with respect to phyletic distributions, functional class, tertiary structures and functionally important residues. Each domain found in a non-redundant protein database as well as search parameters and taxonomic information are stored in a relational database system. User interfaces to this database allow searches for proteins containing specific combinations of domains in defined taxa.

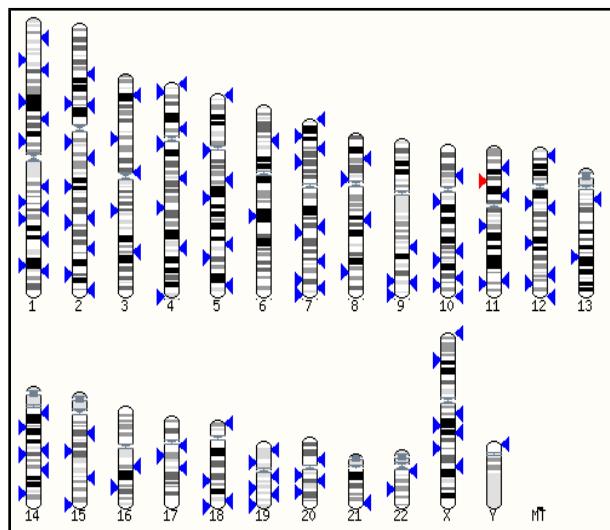
44 **InterPro** is a database of protein families maintained at the **EBI**.

Click on **Display all genes with this domain** for the **Paired_dom** and **Homeobox_InterPro** families. The locations of all genes including each domain will be displayed graphically and textually. **PAX6** is shown in red.

Paired_dom - IPR001523



Homeobox_dom - IPR001356



Which domain, **Paired_dom** or **Homeobox_dom** is more common in humans? _____

How many human **PAX** genes are there? _____

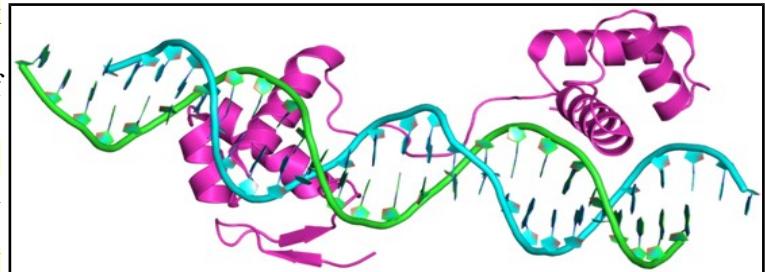
Are all the **PAX** genes on **Chromosome 11**? _____

How does **Interpro** match with the **PAX6 Paralogues** reported by **Ensembl/GeneCards** earlier? _____

Move back to the **Domains & features** display. Link to the **InterPro** database entry for **Paired domain**. Here you will find much confirmation of that which we have already discovered. Click on the **Proteins matched** link. You will see listed a number of representations of proteins that, according to **InterPro**, include a **Paired_dom**. Amongst these will be **P26367⁴⁵**. There are links provided to entries in a number of relevant databases for each listed protein.



Click on the **Structures** link in the top left hand corner of the page. **InterPro** will offer links to relevant entries in the **PDBe**, **SCOP** and **CATH⁴⁶** databases. Click on the link to the **6pax** entry in the **PDBe** database. You will arrive at the entry for **6pax** in **PDBe**, the European version of **PDB** maintained at the **EBI**. Views of this structure are offered on the right hand side of the page. Click on the largest image which shows the paired box protein domain binding DNA rather beautifully. Once you have admired this image sufficiently, move back to the **6PAX PDBe** entry. From the **Quick links** on the right of the page, select the **3D Visualisation** option.

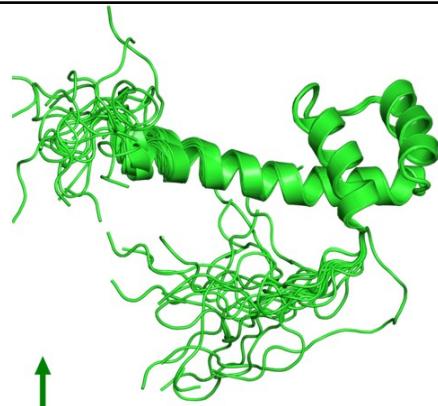


The **Prosite** documentation you read earlier suggested two paired box subdomains, each of which "... form a three-helical fold, with the most C-terminal helices comprising a **helix-turn-helix (HTH)** motif that binds the **DNA major groove**". Move your image around to confirm this assertion.

The same **Prosite** documentation claims the subdomain nearer the N terminal "... encompasses an N-terminal **beta-turn** and **beta-hairpin**, also named '**wing**', participating in DNA-binding. The linker can bind into the **DNA minor groove**'. Manipulate your image to investigate the veracity of these assertions.

45 Third from the bottom of the first page, last time I counted.

46 PDB is the main database of 3D protein structures. SCOP and CATH are also 3D structure databases, we will very superficially visit both later.



Once you have seen all there is to see of **6PAX**, move back to the **Ensembl Domains & features** display. Try the same tricks with the **InterPro homeodomain**. This time, it is difficult to find **P26367** in the huge list⁴⁷ **Proteins matched**, but you do not need to in order to link to the **Structures**. There are many more structures to choose from this time. I suggest you go for **2cue**. You have to imagine the DNA this time.

Can you explain the strangely frayed ends displayed in some of the representations of the **2cue** 3D structure? _____

[Further Features of Ensembl](#)

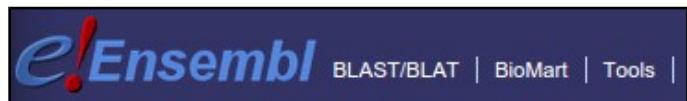


⁴⁷ If you really wanted to, the best approach is to search for **P26367** in the search box at the top of the page and then look for the **homeobox domain** entry in the **Detailed signature matches** list.

Mining Ensembl with Biomart

Used from the **Ensembl** pages, **Biomart** allows the intuitive construction of queries of the entire **Ensembl** database. **Biomart** can be used for various purposes, some of which will be investigated here. The first objective is to use **BioMart** to identify human genes that share specific properties with **PAX6**.

Return to the **Ensembl** homepage (<http://www.ensembl.org>). Click on the **BioMart** link in the banner at the top of the page.



The Start page will enquire which dataset and organism you wish to search. Set **CHOOSE DATABASE** to the latest **Ensembl Gene build** (**Ensembl Genes 81**, as I type). Select **Homo sapiens genes** from the **CHOOSE DATASET** menu..

| |
|--------------------------------|
| Ensembl Genes 81 |
| Homo sapiens genes (GRCh38.p3) |

Click on the **Filters** link to specify the genes of interest.

On this page, enter the following data:

REGION:

Click on the '+' to view the options, but select nothing to search the entire genome. Click on the '-' to tidy the **REGION** options away.

GENE:

Click on the '+'. Check **Transcript count >=** and set the value to **15** to limit to genes with many transcripts only. A trifle arbitrary, but never mind. Transcript count >=

Click on the '-' to tidy the **GENE** options away.

MULTI SPECIES COMPARISONS:

Click on the '+'. Check **Homolog filters** (suppressing, as best you can, justified horror at the truly ghastly transatlantic misspelling!) and set the value to **Orthologous Drosophila Genes** to limit to genes with fly orthologues. Click on the '-' to tidy the **MULTI SPECIES COMPARISONS** options away.

| | |
|---|------------------------------|
| <input checked="" type="checkbox"/> Homolog filters | Orthologous Drosophila Genes |
| <input type="radio"/> Only | |
| <input type="radio"/> Excluded | |

PROTEIN DOMAINS AND FAMILIES:

In this section, turn on **Limit to genes with these family or domain IDs**. Choose **Interpro IDs** as the means of selection.

Enter the two **Interpro ID(s)** of the **PAX6** gene that you noted down earlier⁴⁸

| | |
|--|---------------------------------|
| <input checked="" type="checkbox"/> Limit to genes with these family or domain IDs [Max 500 advised] | Interpro ID(s) [e.g. IPR007087] |
| | IPR001523 IPR001356 |

in a **comma** or **space** separated list. This translates to all proteins with either a **paired box** or a **homeobox** domain, or both.

Click on the **Count** button. You should see that your filtering has selected around **10** genes from the **65,000** or so to which **Ensembl** admits existence. Now click on the **Attributes** button to specify what properties you would like to retrieve for the genes you have selected. Enter the following:

GENE:

Check **Ensembl Gene ID** (default), turn off **Ensembl Transcript ID**
Check **Chromosome Name**

| |
|---|
| <input type="checkbox"/> UniProt/TrEMBL Accession |
| <input type="checkbox"/> UniProt/SwissProt Accession |
| <input checked="" type="checkbox"/> UniProt Gene Name |
| <input type="checkbox"/> UniProt Transcript Name |

| |
|---|
| Ensembl |
| <input checked="" type="checkbox"/> Ensembl Gene ID |
| <input type="checkbox"/> Ensembl Transcript ID |
| <input type="checkbox"/> Ensembl Protein ID |
| <input type="checkbox"/> Ensembl Exon ID |
| <input type="checkbox"/> Description |
| <input checked="" type="checkbox"/> Chromosome Name |

EXTERNAL:

Check **Uniprot Gene Name**

| |
|---|
| <input type="checkbox"/> UniProt/TrEMBL Accession |
| <input type="checkbox"/> UniProt/SwissProt Accession |
| <input checked="" type="checkbox"/> UniProt Gene Name |
| <input type="checkbox"/> UniProt Transcript Name |

PROTEIN DOMAINS AND FAMILIES:

Check **Interpro ID**
Check **Interpro Short Description**

| | |
|--|---|
| Interpro | |
| <input checked="" type="checkbox"/> Interpro ID | <input type="checkbox"/> Interpro start |
| <input checked="" type="checkbox"/> Interpro Short Description | <input type="checkbox"/> Interpro end |
| <input type="checkbox"/> Interpro Description | |

48 OK ... just in case you forgot! IPR001523 and IPR001356.

Click on the **Results** button. By default only the top **10** filtered entries are displayed. Note that some appear to be the same!! They are not however. Some hits differ in features that you have not chosen to display and so give rise to apparent duplications. This phenomena can be eliminated by checking **Unique results only**, try it.

You are not displaying all your hits, so elect to lengthen your results list to **200 rows**. Your list is now complete but will still include more entries than the gene count Ensembl declared to match your search criteria.

Look closely and you will see that only the predicted number of genes are mentioned in the **Uniprot Gene Name** column.

Specifically, the **PAX6** protein (**Gene ID: ENSG00000007372**) will match both **Interpro** families⁴⁹ and so appear at least twice in this list.

| Ensembl Gene ID | Chromosome Name | UniProt Gene Name | Interpro ID | Interpro Short Description |
|-----------------|-----------------|-------------------|-------------|----------------------------|
| ENSG00000148516 | 10 | ZEB1 | IPR001356 | Homeobox_dom |
| ENSG00000177426 | 18 | TGF1 | IPR001356 | Homeobox_dom |
| ENSG00000139624 | 12 | LASS5 | IPR001356 | Homeobox_dom |
| ENSG00000139624 | 12 | CERS5 | IPR001356 | Homeobox_dom |
| ENSG00000090661 | 19 | CERS4 | IPR001356 | Homeobox_dom |
| ENSG00000143190 | 1 | oct-1B | IPR001356 | Homeobox_dom |
| ENSG00000143190 | 1 | POU2F1 | IPR001356 | Homeobox_dom |
| ENSG00000257923 | 7 | CUX1 | IPR001356 | Homeobox_dom |
| ENSG00000134138 | 15 | MEIS2 | IPR001356 | Homeobox_dom |
| ENSG00000143995 | 2 | MEIS1 | IPR001356 | Homeobox_dom |
| ENSG00000169554 | 2 | ZEB2 | IPR001356 | Homeobox_dom |
| ENSG0000007372 | 11 | PAX6 | IPR001356 | Homeobox_dom |
| ENSG00000028277 | 19 | POU2F2 | IPR001356 | Homeobox_dom |
| ENSG00000196092 | 9 | PAX5 | IPR001523 | Paired_dom |
| ENSG0000007372 | 11 | PAX6 | IPR001523 | Paired_dom |

You have information for a number of genes each of which has at least **15** transcripts, includes either a **paired box** domain or a **homeobox** domain (or both) and has **orthologues** in the **Drosophila** genome.

Finally, for this search, move once more to the **Attributes** and turn off everything except the **Ensembl Gene ID**.

| |
|--|
| Filters |
| Transcript count >= : 15 |
| Orthologous Drosophila Genes: Only |
| Interpro ID(s) [e.g. IPR007087]: [ID-list specified] |
| Attributes |
| Ensembl Gene ID |

| View | 200 | rows as | HTML | <input checked="" type="checkbox"/> Unique results only |
|------------------------|-----|---------|------|---|
| Ensembl Gene ID | | | | |
| ENSG00000148516 | | | | |
| ENSG00000177426 | | | | |
| ENSG00000139624 | | | | |
| ENSG00000090661 | | | | |
| ENSG00000143190 | | | | |
| ENSG00000257923 | | | | |
| ENSG00000134138 | | | | |
| ENSG00000143995 | | | | |
| ENSG00000169554 | | | | |
| ENSG0000007372 | | | | |
| ENSG00000028277 | | | | |
| ENSG00000196092 | | | | |

Click on the **Results** button once more. Set the View of **200 rows as CSV**⁵⁰. Set **Unique results only**, although there will be no duplications this time, of course.

In the **Export all results to** section, set the format to **CSV**, choose **Unique results only** and then click **Go**.

| | | | | |
|-----------------------|------|-----|---|-----------|
| Export all results to | File | CSV | <input checked="" type="checkbox"/> Unique results only | Go |
|-----------------------|------|-----|---|-----------|

Do whatever it takes to end up with a file on your **Desktop** called:

Ensembl_Genes_List.txt

containing your gene list.

49 This could be “solved” by not asking for the **Interpro IDs** or **Interpro Short Descriptions** to be displayed. But ... enough!

50 Comma Separated Values

Now try a search of the variations section of the database. The object this time is to list all the **splice acceptor** variations associated with any of the genes listed in the file you have just made from specified chromosomes. A very simple search to set up as you need only specify the file of **Ensembl Gene IDs**, the type of variation that is of interest and the chromosomes of interest.

Start afresh by clicking on the  **New** button in the top left hand corner of your page.

Set **CHOOSE DATABASE** to the latest **Ensembl variation** release (**Ensembl Variation 81** at the time of typing)

| |
|----------------------|
| Ensembl Variation 81 |
| - CHOOSE DATASET - |

Set **CHOOSE DATASET** to **Homo sapiens Short Variation (SNPs and indels)**.

| |
|--|
| <input checked="" type="checkbox"/> Chromosome |
| 1 |
| 2 |
| 3 |
| 4 |
| 5 |
| 6 |
| 7 |
| 8 |
| 9 |
| 10 |
| 11 |
| 12 |
| 13 |

Click on the **Filters** link.

Open the **REGION** section.

Check **Chromosome** and select just chromosomes **10, 11 and 12**.

| |
|---|
| <input checked="" type="checkbox"/> Ensembl Gene ID(s) [Max 500 advised] |
| Browse... Ensembl_Genes_List.txt |
| <input checked="" type="checkbox"/> Consequence type |
| regulatory_region_amplification
regulatory_region_variant
sequence_variant
splice_acceptor_variant
splice_donor_variant
splice_region_variant
splice_site_variant
splicing_variant
start_lost
stop_gained |

Open **GENE ASSOCIATED VARIATION FILTERS**.

Check **Ensembl Gene ID(s)** and **Browse** for the file **Ensembl_Genes_List.txt**

Check **Consequence type** and select **splice_acceptor_variant**

Click **Count**. You should have around **20** hits.

Click on the **Attributes** link.

Open **GENE ASSOCIATED INFORMATION**.

Select **Ensembl Gene ID**

| |
|--|
| For Ensembl Genes |
| <input checked="" type="checkbox"/> Ensembl Gene ID |
| <input type="checkbox"/> Ensembl Transcript ID |
| <input type="checkbox"/> Transcript strand |
| <input type="checkbox"/> Biotype |
| <input type="checkbox"/> Consequence to transcript |
| <input type="checkbox"/> Consequence specific allele |
| <input type="checkbox"/> Protein allele |
| <input type="checkbox"/> Variation start in cDNA (bp) |
| <input type="checkbox"/> Variation end in cDNA (bp) |
| <input type="checkbox"/> Variation start in translation (aa) |
| <input type="checkbox"/> Variation end in translation (aa) |
| <input type="checkbox"/> Variation start in CDS (bp) |
| <input type="checkbox"/> Variation end in CDS (bp) |
| <input type="checkbox"/> Distance to transcript |
| <input type="checkbox"/> PolyPhen prediction |
| <input type="checkbox"/> PolyPhen score |
| <input type="checkbox"/> SIFT prediction |
| <input type="checkbox"/> SIFT score |

Click the  **Results** button.

| View | | 200 | rows as | HTML | <input checked="" type="checkbox"/> Unique results only |
|----------------|------------------|-----------------|--------------------------------|------------------------------|---|
| Variation Name | Variation source | Chromosome name | Chromosome position start (bp) | Chromosome position end (bp) | Ensembl Gene ID |
| rs145772444 | dbSNP | 12 | 50135654 | 50135657 | ENSG00000139624 |
| rs58981907 | dbSNP | 12 | 50134069 | 50134069 | ENSG00000139624 |
| CD983714 | HGMD-PUBLIC | 11 | 31793804 | 31793804 | ENSG00000007372 |
| rs587776571 | ClinVar | 11 | 31793555 | 31793555 | ENSG00000007372 |
| CS982309 | HGMD-PUBLIC | 11 | 31801778 | 31801778 | ENSG00000007372 |
| CS068282 | HGMD-PUBLIC | 11 | 31793554 | 31793554 | ENSG00000007372 |
| CS982311 | HGMD-PUBLIC | 11 | 31793554 | 31793554 | ENSG00000007372 |
| CS951501 | HGMD-PUBLIC | 11 | 31793555 | 31793555 | ENSG00000007372 |
| CS097102 | HGMD-PUBLIC | 11 | 31801777 | 31801777 | ENSG00000007372 |
| CS971847 | HGMD-PUBLIC | 11 | 31794116 | 31794116 | ENSG00000007372 |
| CS068284 | HGMD-PUBLIC | 11 | 31794790 | 31794790 | ENSG00000007372 |
| CS113131 | HGMD-PUBLIC | 11 | 31794790 | 31794790 | ENSG00000007372 |
| CS982308 | HGMD-PUBLIC | 11 | 31802836 | 31802836 | ENSG00000007372 |
| CS094484 | HGMD-PUBLIC | 11 | 31800857 | 31800857 | ENSG00000007372 |
| CS030544 | HGMD-PUBLIC | 11 | 31800857 | 31800857 | ENSG00000007372 |
| CS030312 | HGMD-PUBLIC | 11 | 31793803 | 31793803 | ENSG00000007372 |
| CS971848 | HGMD-PUBLIC | 11 | 31793803 | 31793803 | ENSG00000007372 |
| CS004350 | HGMD-PUBLIC | 11 | 31802836 | 31802836 | ENSG00000007372 |

Set the **View** to **200** rows, **HTML**, **Unique results only**.

Your list represents all the variants available from **Ensembl** that affect the **splice acceptor** sites of the genes that you discovered in your previous **BioMart** search that occur on Chromosome **10, 11 or 12**.

Lastly, to demonstrate the extraction of sequences from **Ensembl**. You have already made a file containing the genomic sequence of the gene **PAX6** for further analysis. This was easily achieved using the **Ensembl** browser interface. However, had you wanted the sequences of all the genes associated with a **homeobox** domain (not far short of **300**) using the browser method would be quite intolerable. With **Biomart**, such an enterprise is trivial, as we will now demonstrate.

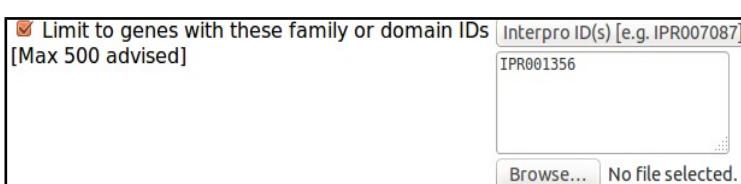
Once again, start afresh. Click on the  **New** button at the top of the page.

Set **CHOOSE DATABASE** to the latest **Ensembl Gene build (Ensembl Genes 80)**, as I type). Select **Homo sapiens genes** from the **CHOOSE DATASET** menu.



Click on the **Filters** link to specify the genes of interest.

Open **PROTEIN DOMAINS AND FAMILIES**.



Check **Limit to genes with these family or domain Ids**.

Choose **Interpro IDs** as the means of selection.

Enter the **Interpro ID** for **homeobox** domains (**IPR001356**).

Click **Count**. You should have around **260** hits.

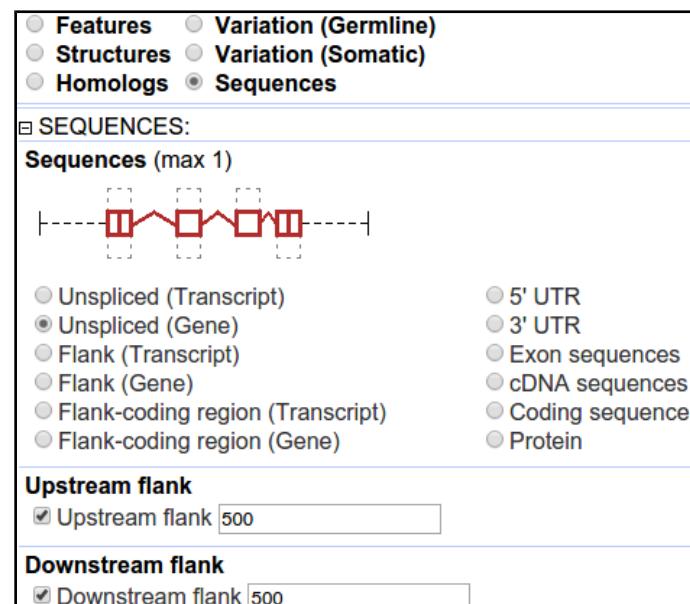
Move to the **Attributes** section and select **Sequences**.

Open the **SEQUENCES** section.

ask for **Unspliced(Gene)**,

with **500** base pairs of **Upstream flank**,

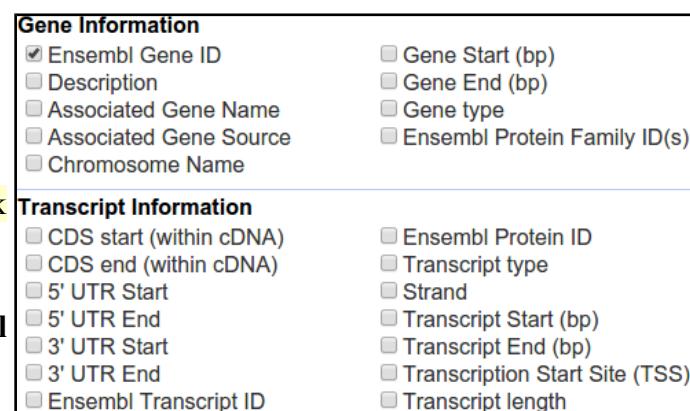
and **500** bases of **Downstream flank**.



That is, all the relevant sequence with an extra bit of on each end.

Now move to the **Header Information** section. Uncheck **Ensembl Transcript ID**.

To include the identifiers of all the transcripts that **Ensembl** predicts for all these genes is far to unwieldy.



Click on the **Results** button

The requested sequences will appear in **Fasta** format with just the **Ensembl Gene ID** in the identification line.

```
>ENSG00000004848
CCGACGCCCGTCCGGCTAGAGAGGACGCCATTGAGGCCAGGGAGGTCAAGGGCGTGT
CTGGGAGCCAATATCGGCTTGAAAAGTGCAGTGAACGTGAGCTCGCCCTCGAGG
CCTGCCCTCAGGGAGCGAGCTCTCGGTTGGTGAAGGGCGCACGCCACCCAGATGG
CATTCACAGGCTGGCATCCAATAAGCTAGAACTTCGCCAACACTAAAGGGTCAAGGG
AGGAGCTGCAGGAAGAGGATAGCGGACTTAGAAAATTGTAACCTAAAAAAAGAAAGAAA
AAAAAGGAAAATTGGCTCTGGCTGCGCCGCCCCACAGGCCGACGCCAGCCGGCTCTGGCGAGC
ATCCAGTCGGCTTTGCGCCGCCACAGGCCGACGCCAGCCGGCTCTGGCGAGC
CAATCAGAGGGCCCTCTAGCACGTGGAGGAGAGACTCCAGAGCTAGGCCCGCTG
CTCACTACACTTGTACCGCTTGCTCTGAGCGCGAGAGGGCGAGCTCGGGCGCA
GGCGGGAGCCGGCAGCCGCAACCAAGGGAGGCAGAAAGGCACAAAGATCGCAATAATA
TCCGTTATAACCGCTATCTAACCCCACCCCCAACACACACCCATCCATCCCACCCCTCG
GGAGAGGCAGCCGGCAGATCCCTCTCGCCCTGGGAAAAGGCCAGCCATGAGCAAT
CACTACCCAGGAGGGCTGCTCCAGGAGGCCAGCTGCAAAGTAAATCTCCAACCTTG
CTCTCCTCTACTGCATCGACAGCATCCCTGGCCGGAGGAGCCCGTGCACAAATGCGGTTG
CTGGGAGCCGGCAGAGCTTGCCTGCTCCGTGACCAGCCGCCGACCCGGAAAAGGCC
GTGCAAGGTAGGATGCTCCGTCAAGGCACTTAAGGGCATGGCCCTGATTGGAT
GTTTGGTGTTCGGGGCCAGTGGCTTGAATTGCAATTGGAGAGGAAGGAAGGAGGAGG
```

In the **Export all results to** section, keep the default option of creating a **File in FASTA** format. Choose **Unique results only** and then click **Go**.

| | | | | |
|-----------------------|-----------------------------------|-------|---|----|
| Export all results to | <input type="text" value="File"/> | FASTA | <input checked="" type="checkbox"/> Unique results only | Go |
|-----------------------|-----------------------------------|-------|---|----|

Do whatever it takes to end up with your **homeobox** sequences in a file on your **Desktop** called:

human_genetic_hox.fasta

Sequence Analysis

The overall target remains to discover all we can about **Aniridia** and its genetic causes. Here we will see how information can be derived from analysis of sequence data directly. Many of the analysis tools and methods we will use and discuss will be those that were used to generate the “ready made” answers you have already investigated. The conclusions of this section should not therefore contradict those you have already reached.

To start the analysis section, you should have data files including:

pax6_primers.fasta

The sequence of the Paired box domain of the most prolific human **PAX6** isoform in a file called:

pax_domain.fasta

The genomic sequence of the whole of the **PAX6** gene, plus an extra 500 bases in each direction, in a file called

pax6_genomic.fasta

The most prolific human **PAX6** isoform in a file called:

pax6_human.fasta

The file **pax6_genomic.fasta** contains the sequence of **PAX6** from a person(s) who, it can be assumed, does not suffer from **Aniridia**. Given a sequence from a person who **does** suffer from **Aniridia**, an obvious first step of investigation might be to compare the sequence from the affected source with the wild type. It would be reasonable to speculate that differences might explain the disease. Here we have to cheat a bit. I have provided an mRNA sequence we will suppose you sequenced from an **Aniridia** patient. It is stored in a file called:

pax6_cdna.fasta

which you will find in a directory called **Working Directory** on your **Desktop**.

Internet resources will be employed for many analyses. Software that runs under windows on your workstation will be used occasionally. All windows software has been installed, without **Administrator** privileges, using an Installer that will be made available to you.

The **EMBOSS** package⁵¹, using a program called **spin**⁵² to provide a **Graphical User Interface (GUI)** will be used for most of the workstation analyses. This is not ideal, particularly as support for **spin** is minimal, but the options⁵³ are few. A feature of **EMBOSS** is that it allows access to remote databases using **SRS**. It is possible to load sequences from any **SRS** server around the world (by default, the **EBI**). I will demonstrate the how to get started with **spin/EMBOSS**. If you have reached this point ahead of my demonstration, try to work it out for yourself. It is not that tricky. Start **Spin** in the usual windows way (it is part of the **The Staden Package**, which is in the **Start menu** under **Sequence Analysis Tools Installer**). Here are a few clues how to proceed.

Before you start analysing sequences, make sure you tell **spin** to manage its files somewhere sensible. Strangely, its default inclination is to create user output files in its installation directory? This is not sensible, so select **Change directory** from the **File** pull down menu and select a more sensible default directory. I suggest you might make a directory in your desktop named as you please for this purpose⁵⁴.

51 Documentation pages for **EMBOSS** can be accessed at the **EMBOSS** home page at:
<http://emboss.sourceforge.net>

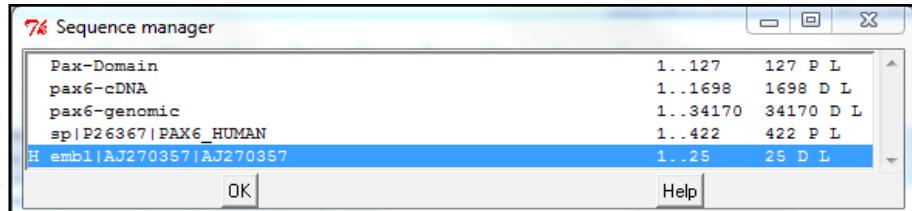
52 A part of the **Staden Package**.

53 That is **FREE** options!

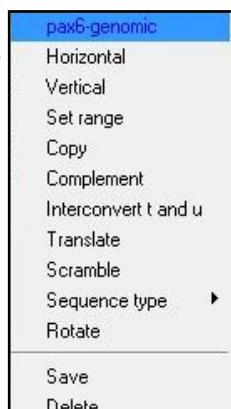
54 It would be very sensible to move **pax6_cdna.fasta** and all the files you have created thus far (**pax6_genomic.fasta**, **pax6_primers.fasta**, **pax_domain.fasta** and **pax6_human.fasta** in particular) into this directory.

Begin by loading all the sequence files you have gathered thus far. From the **File** drop down menu select **Load Sequence** and then **Simple**. This will present a new dialogue box for you to specify a sequence to be loaded. Leave the choice of **Database** as the default **Personal File**, as the all the sequences needed initially are stored in local files. To the right a text box awaits the file path for a sequence file⁵⁵. Use the **Browse** button to find and enter the directory you set up as your default⁵⁶. Select all the sequence files listed above⁵⁷ and click **Open** and then **OK** in the **Load Sequence** window. From this point onwards the package will refer to these sequences by their **fasta** titles (e.g. **pax6-cDNA** and **pax6-genomic**)⁵⁸.

Take some time to become acquainted with the **spin Sequence manager**. This provides access to all loaded sequences. Its main purpose is to enable sequences to be



selected for analysis. From the **File** drop down menu, select **Sequence Manager**. A window will appear listing the sequences showing their start and end, length and type (D for DNA or P for Protein). The last sequence to be loaded will be labelled **H** (for **Horizontal**)⁵⁹. The sequence set to **Horizontal** is the one that **spin** will analyse by default. Ensure that **pax6-genomic** is set to **Horizontal** by right clicking its name and selecting **Horizontal**. Right clicking an entry brings forth a menu offering several more possibilities than we will use in these exercises. For example, it is possible to **Set range**, that is specify regions of entries to be analysed separately. Also it is possible to **Translate** or **Compliment** DNA sequences to create new entities for analysis.



In similar fashion, make **pax6-cDNA** the **V** (for **Vertical**) sequence⁶⁰.

Leave the **Sequence manager** by clicking **OK**. You are now be ready to proceed.

55 If a sequence database had been selected, this box would require an appropriate sequence reference.

56 If you did things correctly, you should be in the right place without having to move anywhere.

57 You can select multiple files in a number of ways including holding the **Ctrl** key down whilst clicking on each of the files you require.

58 **spin** will describe all the sequences it has loaded. Note that only the first of the primer sequences was loaded, sadly **spin** does not recognise that **pax6_primers.fasta** is a multiple sequence file. This will not matter to us as the exercises stand at present.

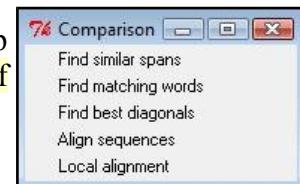
59 This refers, somewhat bizarrely, to the placement of the sequence on Cartesian axes.

60 This only really makes complete sense when you are computing dotplots, which you are just about to do. **spin** is limited in that it allows a maximum of 2 sequences to be selected. When only one sequence is required, the **Horizontal** selection is used.

Pairwise Sequence Comparison

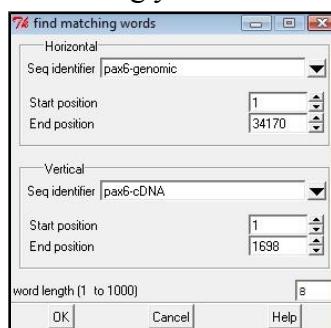
For most of the simple sequence analysis in this section, you will use programs from the **Emboss** package behind the Graphical User Interface (GUI) of the **Staden** Package. However, the native pairwise sequence comparison options of the **Staden** Package are as good as any, and they allow a fuller range of graphical options to be employed. Accordingly, we will use just the **Staden** Package for pairwise sequence comparison here.

You will be using options from **spin's Comparison** menu for the next few steps. To set up that menu for easy access, click on **spin's Comparison** button and then on the dotted line of the menu that will appear. Position the menu window that “tears off” conveniently.

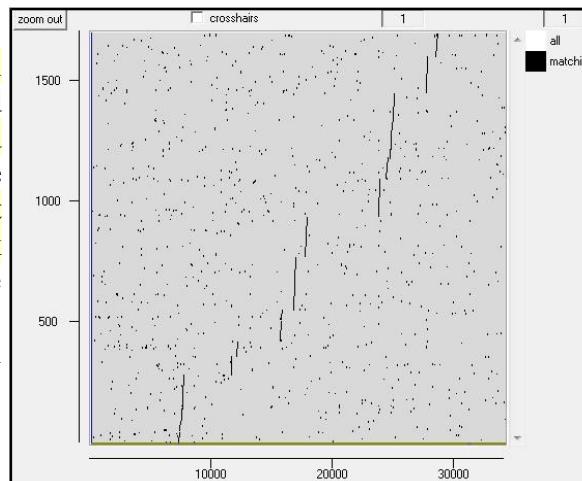


Graphical pairwise sequence comparison - DotPlots

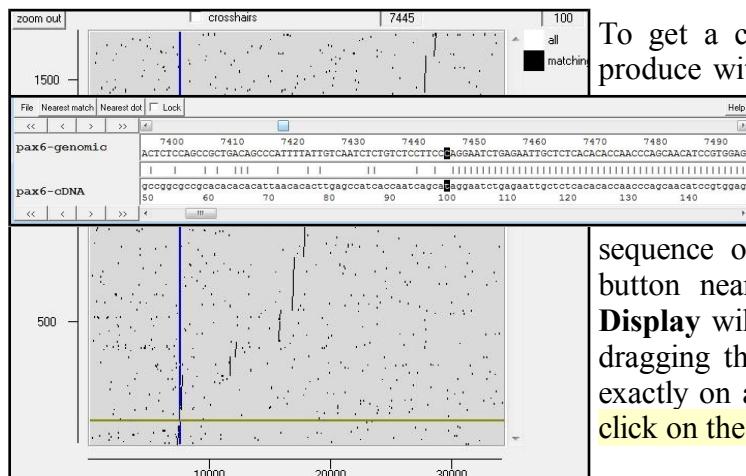
An intuitive graphical representation of the comparison between two sequences is a **dotplot**. One sequence is represented on each of two Cartesian axes and significant matching regions are indicated as a plot. Further detail will be provided by presentation. These plots are used to indicate which sections of sequence might align with each other convincingly and thus warrant further investigation.



From your **Comparison** menu, select **Find matching words**, which offers a simple and fast way to draw a dot plot. Check that you have the sequences you expect in the **Horizontal** and **Vertical** positions⁶¹. Accept the default **word length** of **8**⁶² and click **OK**. A **dotplot** will burst forth with the genomic sequence along the bottom axis, and the cDNA sequence on the vertical axis, as illustrated. As far as the resolution of the picture allows one to judge, there appears to be **11** matching regions.



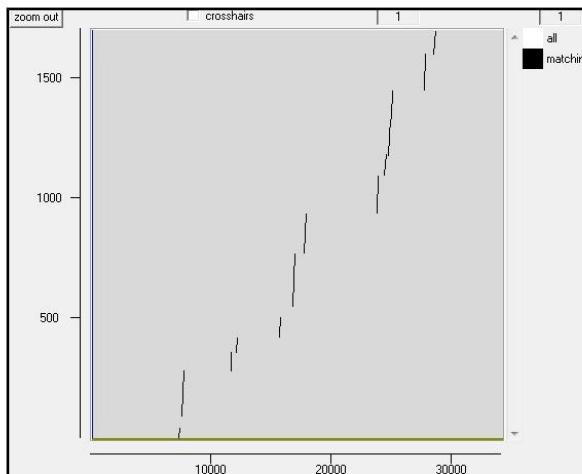
What do you suppose these regions represent?



To get a clearer view of the features of any of the graphics you produce with **spin**, you can always make the picture window bigger, use the **X** and **Y** controls at the bottom to reshape the view, hold the **Ctrl** key down and select a region with your right mouse button to **zoom in** to a feature⁶³. Try any or all of these possibilities. You can also view the sequence of any feature by double clicking your left hand mouse button near that feature. Try this and a **Sequence Comparison Display** will appear. You can control the sequence region in view by dragging the cross hairs that will appear around. To fix the display exactly on a given feature, get as near as you can manually and then click on the **Nearest match** button.

Using a **word length** as small as **8** shows the meaningfully matching regions quite well in this case, but there is quite a bit of unnecessary “noise”⁶⁴. The features we wish to be shown are long, so it is possible to use a bigger word size without losing matches of importance.

Re-run **Find matching words**, exactly as before but this time, select a **word length** of **50**. Your new dotplot will be drawn on top of you first and so will thus be difficult to see. A plot can be repositioned by moving around its configuration button (the corresponding square in the top right hand corner) with the middle mouse button. You could move the new dotplot so it is above or below the first or into a separate window (the best choice) by dragging its configuration button into an unoccupied place on your desktop. Your second plot is



⁶¹ If you need to, use the pull down menus provided to select from any of the sequences in your **Sequence manager**.

⁶² Thus asking the program to indicate the presence of exactly matching regions of **8** base pairs between the chosen sequences.

⁶³ There is a **zoom out** button at the top of the display to undo any **zooming in** you try.

essentially as the first, without the noisy background. Now it looks more like twelve matching regions. We compare genomic sequence with cDNA, so it is reasonable to assume the matching regions of this plot represent the exons found in a transcript of **PAX6**.

[Is the number of matching regions consistent with the number of exons you might expect?](#)

[If not, can you explain the discrepancy?](#)

The second plot is clearer. Noise has been eliminated without loss of “real” features. The choice is not always so clear. It can be necessary to experiment using different parameters.

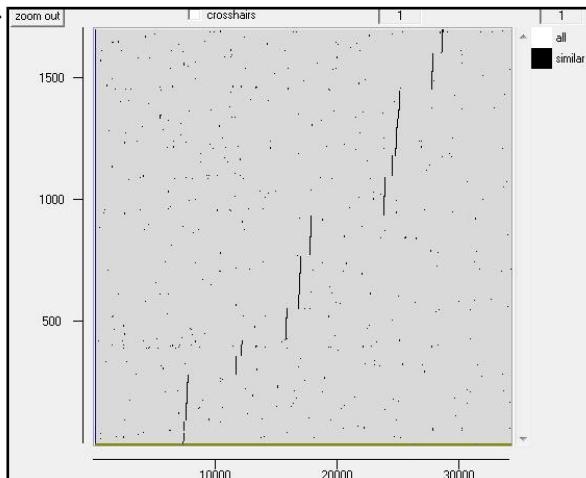
The algorithm you have used thus far is fast but crude. Adequate for these sequences between which all real matches are long and almost exact. However, in most circumstances a more meticulous slower⁶⁵ approach might be required in which “similar” as well as exactly matching words are recognised. From your **Comparison** menu, select **Find similar spans**, accepting the default **window length** of **11** and **minimum score** of **10**⁶⁶, click **OK**⁶⁷. Your plot should be as illustrated.

Again, from your **Comparison** menu, select **Find similar spans**. This time, set the **window length** to **50**. **spin** automatically resets its **minimum score** field to a new default of **28**. Click **OK**. Separate out your new plot so that it can be seen clearly. No surprises? A less noisy background is the most obvious effect. Also you should be able to see that the “real” features appear to have grown a little.

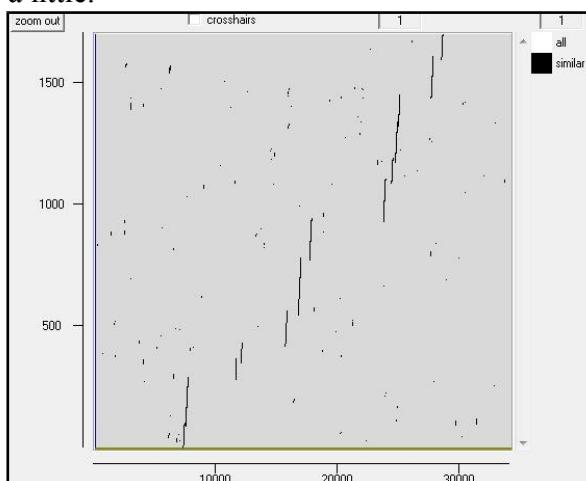
[Why do you suppose that might be?](#)

The dotplot can be useful as a rapid overview of the similarity between two sequences. Alone, it provides insufficient detail. For this, we need to generate textual alignments.

spin produces helpful graphics when textually aligning sequences. These graphics are most informative when superimposed over a corresponding dotplot. Here, the most useful dotplot is the simplest. The one you generated using the “**Find matching words**” algorithm with a word length of **50**. If you have not already done so, throw all the others away. If necessary, recreate the required dotplot.



Pairwise textual sequence alignment



Now make some alignments that will show the detail of the dotplot comparisons. The algorithms used are more rigorous than those used for searching databases, often producing more revealing alignments. Thus it can be a good idea to use these tools on similar sequences identified by database similarity searches

Global sequence alignment

A global alignment is one that aligns two sequences over their entire lengths. In **spin's Comparison** menu, the option **Align sequences**⁶⁸. Click on **spin's Align sequences** option. Click **OK** accepting the defaults⁶⁹:

| | | |
|--|------|--|
| score for match | (4) | value added to the alignment score for each correctly matched base |
| score for mis-match | (-2) | value added to the alignment score for each incorrectly matched base |
| penalty for starting gap | (8) | value subtracted from the alignment score for each gap |
| penalty for each residue in gap | (1) | value subtracted from the alignment score for each element of a gap beyond the first |

spin represents the computed alignment graphically, over the dotplot. It should suggest that it has successfully aligned the group of exons around **23,500** to **25,000** in the genomic sequence and **940** to **1,450** in the mRNA⁷⁰, but then failed with the rest.

⁶⁴ I.e. dots that do not represent anything interesting.

⁶⁵ Not that the speed difference will be apparent with sequences of the size we are comparing here.

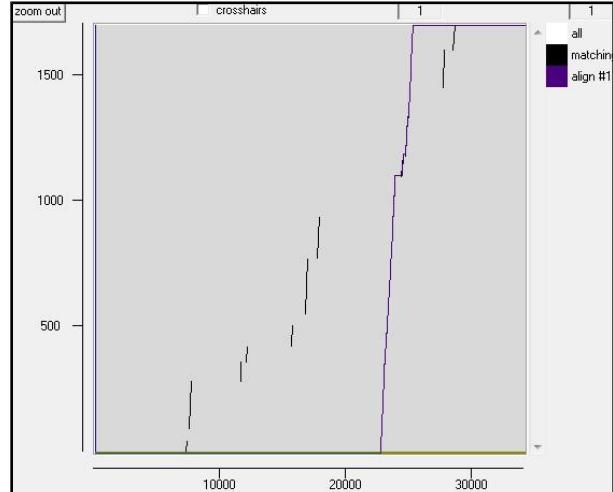
⁶⁶ Thus matched windows of length **11** in which **10** of the aligned bases are identical are regarded as significant. By default, **spin** awards **1** point to matching bases and **0** points to mismatched bases. The equivalent program in the **EMBOSS** package, **dotmatcher**, awards matching bases **+5** and penalises mismatched bases **-4**. The full **EMBOSS** default DNA comparison scoring matrix can be found in an appendix.

⁶⁷ Depending how you left you displays, you might need to separate out your dotplots in order to see them clearly.

⁶⁸ The **EMBOSS** package offers the program **needle**, which is a rigorous implementation of the Needleman-Wunsch algorithm for global alignment. **EMBOSS** also offers a less rigorous (i.e. faster and sloppier) program called **stretcher**.

⁶⁹ A complete description of these parameters will be included in a presentation. Soon, if it has not already occurred.

⁷⁰ Click in the **crosshair** box and use the crosshair to get a good idea of where features are in your plots. I think the cross-hair is very irritating to leave active, so I suggest you click it off again once its purpose is fulfilled.



Examine how your alignment graphic matches the dotplot by right clicking its configuration button and using the **Hide/Reveal** option.

| | | | | | |
|--|-------|-------|-------|-------|-------|
| 23580 | 23588 | 23596 | 23605 | 23615 | 23625 |
| pax6-genomic ATA...ATGCTCTT.GGA.GTTAA.GACTACACCAGGCCCTTCTGGAGGCTCCAGGTT | | | | | |
| | | | | | |
| pax6-cDNA gtatgataaaactaggatgttgaacggccaggg.c. ggaatctgggcacccggccctgggt | 843 | 853 | 863 | 873 | 882 |
| - - - - - | | | | | |
| 23650 | 23656 | 23666 | 23676 | 23676 | 23676 |
| pax6-genomic ...ATCCAA...ATTCTCTTAC...CATCTATTCTTTGTTCAGATGGCTGCCAG | | | | | |
| | | | | | |
| pax6-cDNA ggtatccggggacttcggtgcacggcaacctcgca..... agatgtggctggccagc | 902 | 912 | 922 | 932 | - |
| - - - - - | | | | | |
| 23686 | 23696 | 23706 | 23716 | 23726 | 23736 |
| pax6-genomic AACAGGAAAGGAGGGAGAGAATACCAACTCCATCAGTICCAACGGAGAAGATTCAAGATG | | | | | |
| | | | | | |
| pax6-cDNA aacaggaaaggggggggagagaataccacccatcgatcgtaacaggagataggatcgatg | 953 | 963 | 973 | 983 | 993 |
| - - - - - | | | | | |
| 23746 | 23756 | 23766 | 23776 | 23786 | 23796 |
| pax6-genomic AGGCTCAAATGCGACTTCAGCTGAAGCGGAAGCTGCAAAAGAAATAGAACATCCTTACCC | | | | | |
| | | | | | |
| pax6-cDNA aggcttaatcgacttcagctgaaggcgaaatcgcaaaaatagaacatccattttaccc | 1013 | 1023 | 1033 | 1043 | 1053 |
| - - - - - | | | | | |
| 23806 | 23816 | 23826 | 23836 | 23846 | 23856 |
| pax6-genomic AAGAGCAAATTGAGGCCCTTGAGAGAAGGGTAGAGATAGAGITTTCTAAAGTAGAGAACAGTAA | | | | | |
| | | | | | |
| pax6-cDNA aagagcaaatggggcccttgagaaag..... | 1073 | 1083 | 1093 | - | - |
| - - - - - | | | | | |
| 23866 | 23876 | 23886 | 23896 | 23906 | 23916 |
| pax6-genomic ATCAAGTAATGCCAACITCTAGTACAAAGAGCTAAATTAGCCAGGGCCCTTGTGAT | | | | | |
| | | | | | |
| pax6-cDNA | - | - | - | - | - |
| - - - - - | | | | | |
| 23926 | 23936 | 23946 | 23956 | 23966 | 23976 |
| pax6-genomic AGAAGAATGAAAAGATTCTTTCTTCTGCTCTTTTATCTCTGGCATCTTTCAGTG | | | | | |
| | | | | | |
| pax6-cDNA | - | - | - | - | - |
| - - - - - | | | | | |
| 24586 | 24596 | 24606 | 24616 | 24626 | 24636 |
| pax6-genomic GCAGCAGTGGAGGTGCCAAGGTGGGCTGGCTCGACGTAGACACAGTGTAACTCTGTC | | | | | |
| | | | | | |
| pax6-cDNA | - | - | - | - | - |
| - - - - - | | | | | |
| 24646 | 24656 | 24666 | 24676 | 24686 | 24696 |
| pax6-genomic CACCTGATTTCAGGTATGGTTCTATACTGAAGGCCAATGGAGAAGAGAAAAAC | | | | | |
| | | | | | |
| pax6-cDNA tggttttttatcaatcgaaatggggcaatggggaaatggaaaaaac | - | - | 1189 | 1209 | 1219 |
| - - - - - | | | | | |
| 24706 | 24716 | 24726 | 24736 | 24746 | 24756 |
| pax6-genomic TGAGGAATCAGAGAACAGGCCAGCACACACCTAGTCATATTCTTATCAGCAGTAGTT | | | | | |
| | | | | | |
| pax6-cDNA tgggaaatcagaaatggggccaggccagcaacacccatctgtatccatattttatcagcgttgtt | 1229 | 1239 | 1249 | 1259 | 1269 |
| - - - - - | | | | | |
| 24766 | 24776 | 24786 | 24796 | 24806 | 24816 |
| pax6-genomic TCAAGCACCAGTCTACCAACCAATTCCACACCCACACCCGGTATTTGAAATTCT | | | | | |
| | | | | | |
| pax6-cDNA tcagccccatgttgtatccaaaaatccatccacaaaaatccacccacccacccacccgg..... | 1289 | 1299 | 1309 | 1319 | 1329 |
| - - - - - | | | | | |
| 24826 | 24836 | 24846 | 24856 | 24866 | 24876 |
| pax6-genomic AATAACTACGAATCAATGCTTTAACCTGTTCTCCGGGCTCTGACTCTCACITGACT | | | | | |
| | | | | | |
| pax6-cDNA | - | - | - | - | - |
| - - - - - | | | | | |
| 24886 | 24896 | 24906 | 24916 | 24926 | 24936 |
| pax6-genomic ACTGTCATTCTCTTGCCTCAGTTCTCTTCACATCTGGCTCCATGTTGGGGCGAC | | | | | |
| | | | | | |
| pax6-cDNA ttctccctccatcatcggtccatgtttggccggccaaat | - | - | 1341 | 1351 | 1361 |
| - - - - - | | | | | |
| 24946 | 24956 | 24966 | 24976 | 24986 | 24996 |
| pax6-genomic AGACACAGCCCTCACAAACACCTCACGCCCTCTGGCCCTATGCCAGCTTACCATGGC | | | | | |
| | | | | | |
| pax6-cDNA agacacagccctcacaaacacccatcgccgttccgtccatgcggatccatcaccatgc..... | 1371 | 1381 | 1391 | 1401 | 1411 |
| - - - - - | | | | | |
| 25006 | 25016 | - | - | 25038 | 25043 |
| pax6-genomic AAATAACCTGCTTATGCAA..... GTAAAGTCGGGCTGTTGGCTGCCATGCA | | | | | |
| | | | | | |
| pax6-cDNA aaataacccatgttgtatccaaaaatccatccacaaaaatccacccatccatctacta....ccgtcgat | 1431 | 1441 | 1451 | 1461 | 1471 |
| - - - - - | | | | | |
| 25053 | 25059 | 25067 | 25076 | - | 25089 |
| pax6-genomic A...CCCA...GCC...CAGAGAA...GTAGAGGAGTGG.....CT.CAGGGCC.....TG | | | | | |
| | | | | | |
| pax6-cDNA ctggcccccacccatcgcccttgcgttgaatggccggatgttatgcacatccatcacc..... | - | - | - | - | - |

Right click on your alignment in spin's **Output window**. The popup menu that appears invites you to:

Show input parameter to record these is vital if your results are to be reproducible.

Output to disk it is important to save your successful results for the

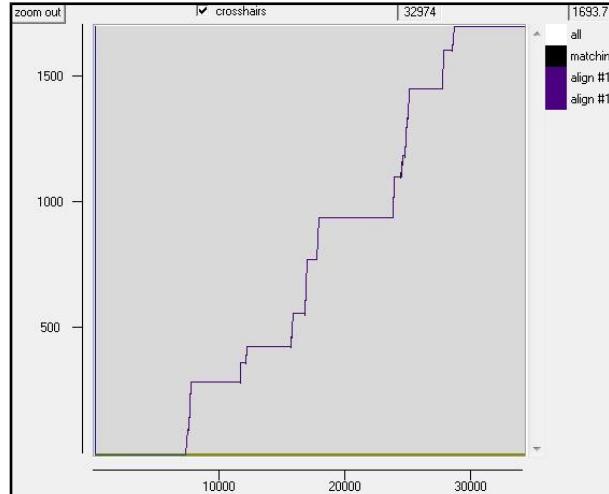
Remove long term
not everything deserves perpetuity

Try these options, first **Show input parameters** which will appear *at the top of your alignment*

Save your alignment, including the **header** and **parameters**, into a file **global_results01.txt** by selecting **Output to disk**¹¹

Finally Remove the alignment from spin's Output window it was a nonsense anyway!

⁷¹ For the Ontario-based Ontario Energy Board, see www.oeb.ca; the Canadian Electricity Association, see www.cea.ca.



Try the alignment again, this time with much “cheaper” gaps. First **Hide** the plot associated with your first global alignment attempt. This should leave the dotplot in clear view. Now click on **spin's Align sequences** option once again. This time, set the **penalty for each residue in gap** to **0**. This amounts to asking that all gaps be penalised exactly **8** points no matter how long they be. Click **OK**.

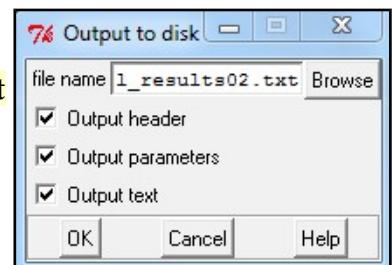
Now the alignment graphic shows the alignment dutifully passing through all the matching regions identified by the dotplot. Take a look at the textual output associated with this second alignment.

How many matching regions are there this time? _____

Is the count now roughly as you would expect? _____

Right click on your alignment in **spin's Output window**, and select **Show input parameters** as previously⁷².

Save your results, with **header** and **parameters**, in a file⁷³ called **global_results02.txt**.



These global alignments show how misleading it can be to run programs without carefully considering their assumptions and parameter values. The second time around, you achieved the “correct” alignment, but only by making the cost of gaps so cheap that huge introns could be mistaken for normal insertion/deletion events. This only worked because the mRNA/genomic sequences came from the same organism and the corresponding exons were effectively identical⁷⁴. If the comparison was between homologous sequences from different organisms⁷⁵, it would usually be necessary to use gap penalties that reflected the way real insertion/deletion events occurred in the exons. Declaring almost free gaps to cope with introns would rarely succeed⁷⁶.

The best solution is to accept that the alignment between a cDNA/mRNA and genomic sequence is a special case. A general alignment program will not make the right assumptions for such alignments and is thus the wrong tool for the job. There is a program in the **EMBOSS** package, called **est2genome**, which is specifically designed for the alignment of cDNA/mRNA and genomic sequences. **est2genome** (and similar programs) may assume much more about the sequences it is given to align than a general purpose alignment program. Gaps representing introns can be placed far more accurately if they are **known** to represent introns. Programs such as **est2genome** seek the highly conserved bases that occur at intron/exon boundaries, C/T rich intronic regions, polyA regions and **Stop/Start** codons to assist its detection of exons and gene structures.

est2genome is a fine program⁷⁷, but there are two other options offered at the **NCBI**⁷⁸ in America that do the same job, I think, somewhat more nicely. Of these, I choose the program called **splign** for this exercise on the grounds it is the more sophisticated service⁷⁹. To investigate, go to the home of **splign** at:

<http://www.ncbi.nlm.nih.gov/sutils/splign>

72 If you do not first **Show input parameters**, they will not be recorded in the results file you create with the **Output to disk** option.

73 Right click in your **spin Output window**, as before. Elect to save the **header** and **parameters**.

74 and so would align correctly given almost any gap penalties, or other parameter settings that might have been chosen.

75 Comparing mRNA from one organism with genomic sequence from another is one way of investigating gene structure in the genomic sequence.

76 One very simple solution to this problem offered by the **GCG** (now defunct) package version of **needle** (a program called **gap**) was to offer a gap penalty ceiling. The program would compute a gap penalty in the normal way until a given “cut off” was reached. **gap** would then assume it was trying to stretch over an intron rather than allow for an insertion/deletion, so it would allow the gap to increase at will without further raising the penalty. This worked much better than my intuition suggested it should!

77 Should you have time, why not try it? It is in the **Alignment/Global** menu. You have to reorder the sequence selections so that the EST sequence (**pax6**) comes first. This is not obvious I am afraid, a place where **EMBOSS** and **Staden** are joined clumsily. Also, it is good to turn on **Show the alignment** in the **Output section**.

78 National Center for Biotechnology Information. A national resource for molecular biology information, **NCBI** creates public databases, conducts research in computational biology, develops software tools for analyzing genome data, and disseminates biomedical information.

79 The other is called **spidey**. Try it if you have time. The **spidey** home page is:

<http://www.ncbi.nlm.nih.gov/IEB/Research/Ostell/Spidey/>

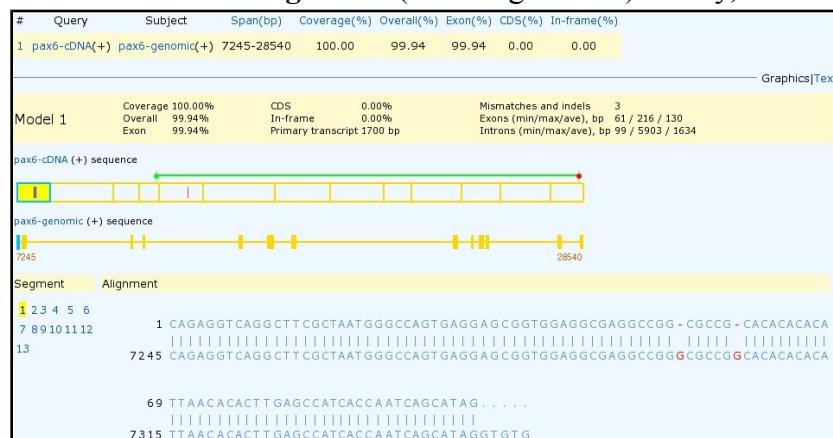
If you have time, why not try it out? It is pretty straight forward, so just follow your nose. **est2genome**, **splign** and **spidey** should all give the same answer for this simple alignment and very similar answers for all such problems.

Click on the **Online** button. In the **Genomic** section, use the **Browse** button to upload **pax6_genomic.fasta**. Into the **cDNA** section, cut and paste the contents of the file **pax6_cdna.fasta**. Note the option **Use discontinuous megablast**. Where **cDNA** and **Genomic** sequences share exons that are nearly identical, **splign** uses a comparison program called **megablast**. When the exons are less close, as they would be if the **cDNA** and **Genomic** sequences were from different organisms, the slightly more sensitive option **discontinuous megablast**, would be a better choice⁸⁰. Note the option to compare your **cDNA** with a **Whole genome** (including Human).

Please specify input sequences by GI/Accession or in FASTA format
Examples (click to select):

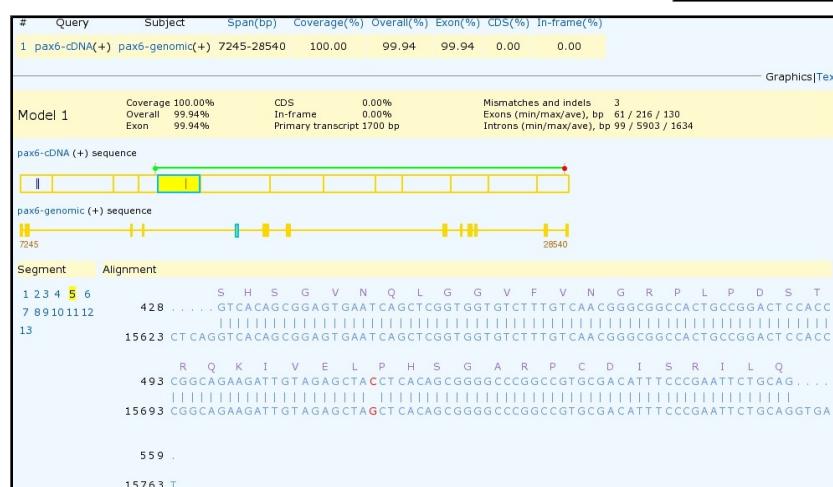
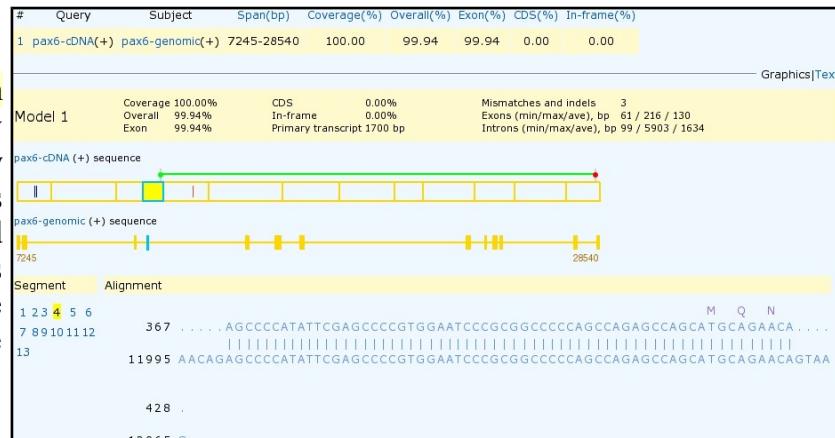
- NM_214647 / NW_732498 (one model)
- AF238306 / NT_033772 (one model, frameshifts)

cDNA with a **Whole genome** (including Human). Today, the default options are fine. Click the **Align** button.



After a short wait, your results will appear showing the cDNA split into **13** sections (the predicted exons) corresponding to **13** regions of the genomic sequence indicated by yellow filled rectangles. The first exon alignment is displayed showing two cDNA deletions. These are unlikely to be very important as we know (from Ensembl) that the first few exons are not coding. The **Start** (green) and **Stop** (red) codons of the cDNA are illustrated by the bar above the cDNA display.

Click on the exon including the green **Start** codon (the fourth). The first coding exon is now displayed. The statistics at the top of the display include the claim that there are three discrepancies (**Mismatches and indels⁸¹**) between the cDNA and Genomic sequences. Two of these are the deletions we have already seen in the first exon of the cDNA. The third is indicated by the red bar in the fifth exon of the cDNA display.



Click on the fifth exon section of the cDNA display.

The third difference, a substitution, should be clear to see. Given it changes the coded protein, this substitution is likely to be the most significant.

What is the amino acid corresponding to this position in the mRNA of the aniridia patient³²?

⁸⁰ Why this is so will be considered later when we look at the database searching program **blast**.

81 An **indel** is either an **insertion** or a **deletion**, depending upon which of the aligned sequences you are considering.

82 The effect the substitution has on the protein is not clear. It would have been handy if the **Genomic** sequence was translated as well as the **cDNA** maybe? The answer will be revealed later. If you cannot wait, the standard Genetic Code is in an Appendix. Or, you could look back to where you considered this mutation when viewing the **Uniprot** feature table for **PAX6 HUMAN**. It is the one at amino acid position **33**.

| # | Query | Subject | Span(bp) | Coverage(%) | Overall(%) | Exon(%) | CDS(%) | In-frame(%) |
|---|--------------|----------------------------|----------|-------------|------------|---------|--------|-------------|
| 1 | pax6-cDNA(+) | pax6-genomic(+) 7245-28540 | 100.00 | 99.94 | 99.94 | 0.00 | 0.00 | |

Graphics|Text

Model 1

| Coverage | 100.00% | CDS | 0.00% | Mismatches and indels | 3 |
|----------|---------|--------------------|---------|---------------------------|------------------|
| Overall | 99.94% | In-frame | 0.00% | Exons (min/max/ave), bp | 61 / 216 / 130 |
| Exon | 99.94% | Primary transcript | 1700 bp | Introns (min/max/ave), bp | 99 / 5903 / 1634 |

pax6-cDNA (+) sequence

pax6-genomic (+) sequence

Segment Alignment

```

 1 2 3 4 5 6   G L I S P G V S V P V Q V P G S E P D M S Q
 7 8 9 10 11 12 1601 ..... GACTCATTTCCCCTGGTGTGTCAGTCCAGTTCAAGTCCCGGAAGTGAACCTGATATGTCCAA
 13           28438 TCTAGGACTCATTTCCCCTGGTGTGTCAGTCCAGTTCAAGTCCCGGAAGTGAACCTGATATGTCCAA
          Y W P R L Q *
 1666 TACTGGCCAAGATTACAGTAAAAAAAAAAAAAA
 28508 TACTGGCCAAGATTACAGTAAAAAAAAAAAAAA
  
```

Click on the last exon section in the cDNA display. You should now see the final exon of the cDNA with the **Stop** codon and polyA region.

| # | Query | Subject | Span(bp) | Coverage(%) | Overall(%) | Exon(%) | CDS(%) | In-frame(%) | | | |
|---|--------------|----------------------------|--------------|-------------|------------|---------|--------|-------------|-------|------------|------------|
| 1 | pax6-cDNA(+) | pax6-genomic(+) 7245-28540 | 100.00 | 99.94 | 99.94 | 0.00 | 0.00 | | | | |
| | | | | | | | | | | | |
| | # | Query | Subject | Idty | Len | Q.Start | Q.Fin | S.Start | S.Fin | Type | Details |
| | +1 | pax6-cDNA | pax6-genomic | 0.981 | 103 | 1 | 101 | 7245 | 7347 | <exon>GT | M53IM5IM43 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 188 | 102 | 289 | 7447 | 7634 | AG<exon>GT | M188 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 77 | 290 | 366 | 11537 | 11613 | AG<exon>GC | M77 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 61 | 367 | 427 | 12000 | 12060 | AG<exon>GT | M61 |
| | +1 | pax6-cDNA | pax6-genomic | 0.992 | 131 | 428 | 558 | 15628 | 15758 | AG<exon>GT | M86RM44 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 216 | 559 | 774 | 16686 | 16901 | AG<exon>GT | M216 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 166 | 775 | 940 | 17606 | 17771 | AG<exon>GT | M166 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 159 | 941 | 1099 | 23674 | 23832 | AG<exon>GT | M159 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 83 | 1100 | 1182 | 24348 | 24430 | AG<exon>GT | M83 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 151 | 1183 | 1333 | 24660 | 24810 | AG<exon>GT | M151 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 116 | 1334 | 1449 | 24909 | 25024 | AG<exon>GT | M116 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 151 | 1450 | 1600 | 27602 | 27752 | AG<exon>GT | M151 |
| | +1 | pax6-cDNA | pax6-genomic | 1 | 98 | 1601 | 1698 | 28443 | 28540 | AG<exon>AA | M98 |

Finally, click on the **Text** link to view the textual summary of the **splign** results.

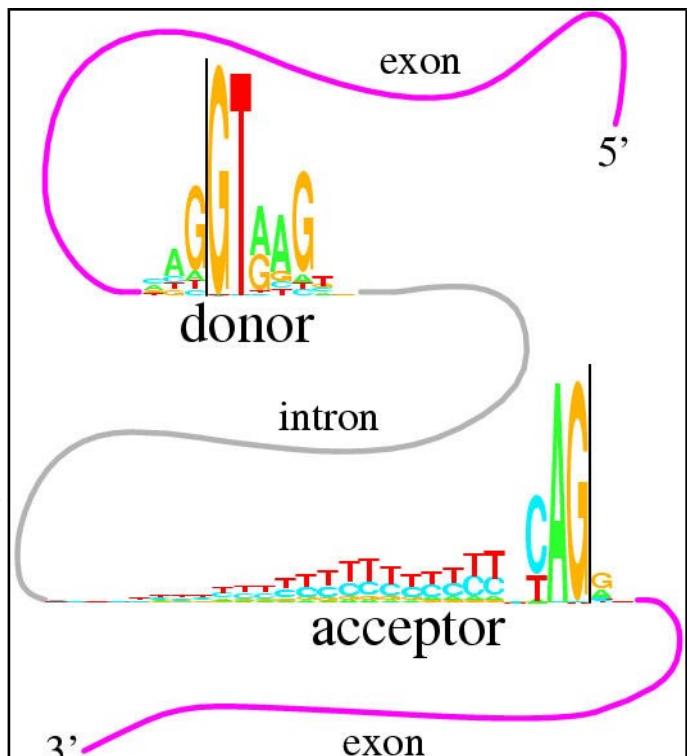
How do you interpret the **Details** column for exons 1 and 5?

Where is the substitution in the aniridia patient mRNA?

Where is the substitution in the Genomic Sequence?

Would you agree there is fine agreement between the **splign** prediction and the intron start/end conservation suggested by the illustration⁸³?

What deviation(s) from the model suggested by the graphic can you see?



83 The original label for this very nice graphic is:

This figure shows two “sequence logos” which represent sequence conservation at the 5’ (donor) and 3’ (acceptor) ends of human introns. The region between the black vertical bars is removed during mRNA splicing. The logos graphically demonstrate that most of the pattern for locating the intron ends resides on the intron. This allows more codon choices in the protein-coding exons. The logos also show a common pattern “CAG|GT”, which suggests that the mechanisms that recognize the two ends of the intron had a common ancestor. See R. M. Stephens and T. D. Schneider, “Features of spliceosome evolution and function inferred from an analysis of the information at human splice sites”, J. Mol. Biol., 228, 1124-1136, (1992).

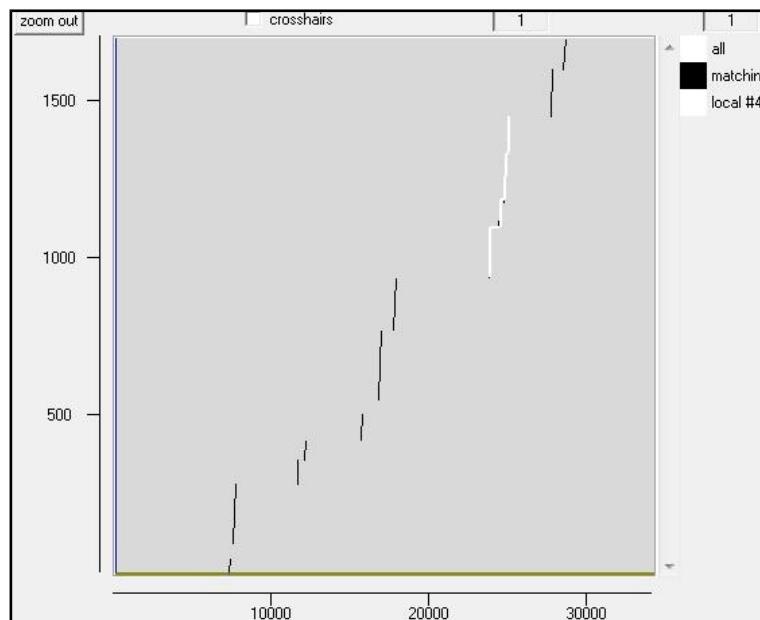
Local sequence alignment

Global sequence alignment algorithms align sequences over their entire lengths. Local alignment methods searches for regions of similarity and need not include the entire length of the sequences. It is important to select the type of alignment that makes best sense for your sequences. In this instance, we expect an ordered sequence of matching regions (the exons) to occur in both sequences but spaced very differently. With an effort (or preferably appropriate software), we can get reasonably sensible alignments using a global or a local approach. However, if our sequences represented multidomain proteins that shared some domains but not others, or proteins where there have been regions of duplication, a single global alignment simple would not exist. A local approach would be essential.

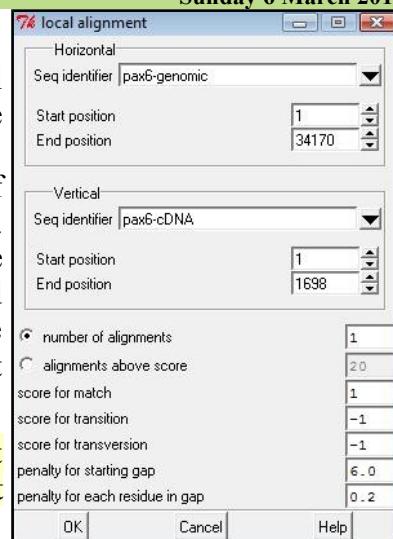
Move back to **spin**, tidy away all previous graphics plots except one clear dotplot between **pax6-genomic** and **pax6-cDNA**. From **spin**'s **Comparison** menu, select **Local alignment**. Note that:

- in common with most local alignment programs, the default **number of alignments** to be reported is 1⁸⁴
 - transversions and transitions may be penalized differently
 - gaps are slightly cheaper than for global alignments

Accept all the defaults and click **OK**. The graphic suggests that the single “best” region that **spin** has elected to locally align, is the region around **25,000** in the genomic sequence where there are **4** exons that are close together. It was this region around which the global alignment algorithm chose to build its first attempt.



Check that the textual and graphic outputs agree. Save your results in a file called **local_results01.txt** (Right click in spin's **Output window** and **Output to disk⁸⁵**).



24332 24342 24352 24362 24372 24382
 pax6-genomic CAACTTACITCITTCAGAGTTGAGAGAACCCATTATTCAGATGTTTGCCCCGAGAAAAGA
 pax6-cDNA
 - - 1104 1114 1124 1134

 24392 24402 24412 24422 24432 24442
 pax6-genomic CTAGCAGCCAAAATAGATCTACTTGAAGCAAGAATACAGGTACCGAGAGACTGTGCACTT
 pax6-cDNA cttagccaaaatagatcttacgtgaagcaagaatacaggta.....
 1144 1154 1164 1174 1184 -

 24452 24462 24472 24482 24492 24502
 pax6-genomic TOACACTTGTGATTCACTACCATTGTTCTAGAGACAGGGTGCTGTACAGAGTA
 pax6-cDNA
 - - - - - -

 24512 24522 24532 24542 24552 24562
 pax6-genomic CTAACTTAACTATAGGACTAACTATAAAAGGTCTAGCTGCTAAATGCCTGCTGCCA
 pax6-cDNA
 - - - - - -

 24572 24582 24592 24602 24612 24622
 pax6-genomic TGGGCGTGGGGAGGGCACAGTGGAGGTGCCAAGGTCTGGGCTCTGACGTGACACA
 pax6-cDNA
 - - - - - -

 24632 24642 24652 24662 24672 24682
 pax6-genomic GIGCTAACCTGCTCCACCTGATITCCAGGTAAAGTTCTAACTGAAAGGGCCAATGGAG
 pax6-cDNA
 - - - - 1195 1205

 24692 24702 24712 24722 24732 24742
 pax6-genomic AAGAGAAAAAAACTGAGGAATCAGAGAAGACAGGCCAACACCTAGTCATATTCC
 pax6-cDNA aagaaagaaaaactgaggaaatcgagagaaagacagggccagcacacaccatgtcatattcc
 1215 1225 1235 1245 1255 1265

 24752 24762 24772 24782 24792 24802
 pax6-genomic TATCAGCAGTAGTTCAACCCAGCTGTCACCAACCAATTCCACACCCACACCGGG
 pax6-cDNA tatcagcagtagtttcagcaccatgcgttccatccaaccatccacacccacccacccgg
 1275 1285 1295 1305 1315 1325

 24812 24822 24832 24842 24852 24862
 pax6-genomic TAATTGAAATACTAACTACGAATCAATGCTTTAACCTGTGCTGGGCTCTGAA
 pax6-cDNA
 - - - - - -

 24872 24882 24892 24902 24912 24922
 pax6-genomic CTCCTACITCAGTACTGTCAITCTCTGCCCCTCAGTTCTCTCACATCTGGCTCC
 pax6-cDNA
 - - - 1337 1347

 24932 24942 24952 24962 24972 24982
 pax6-genomic ATGTTGGGCCAACAGACACAGCCTCAACACACCTACAGCGCTCTGCCCTATGCCC
 pax6-cDNA atgttggccgcacagacacagcgcctccacaaacacctacagcgcgtctgcgcgcctatgcc
 1357 1367 1377 1387 1397 1407

 24992 25002 25012 25022
 pax6-genomic AGCTTACCATGCGAACATAACCTGCCTATGCCA
 pax6-cDNA agcttccatcatgcggaaataaccctgcctatgcc
 1413 - 1423 - 1433 - 1443

The choice of this region is primarily due to the choice of gap penalties. If bigger gap penalties were selected (increase **penalty for each residue in gap** to 1, say) **spin** would cease to regard the **4** exons around **25,000** as one entity. Their individual alignment scores would look less attractive. Eventually, the region around **16,700** (the longest single exon) would easily outscore the rest. If you have time, try it.

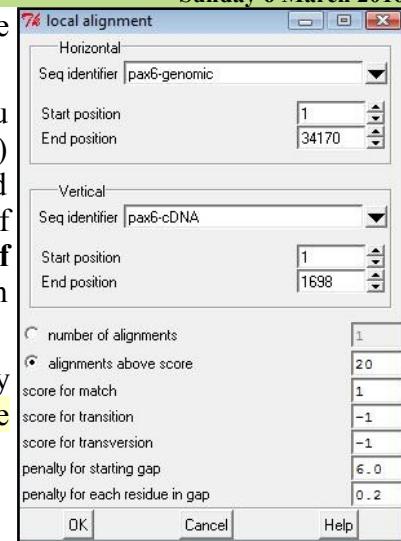
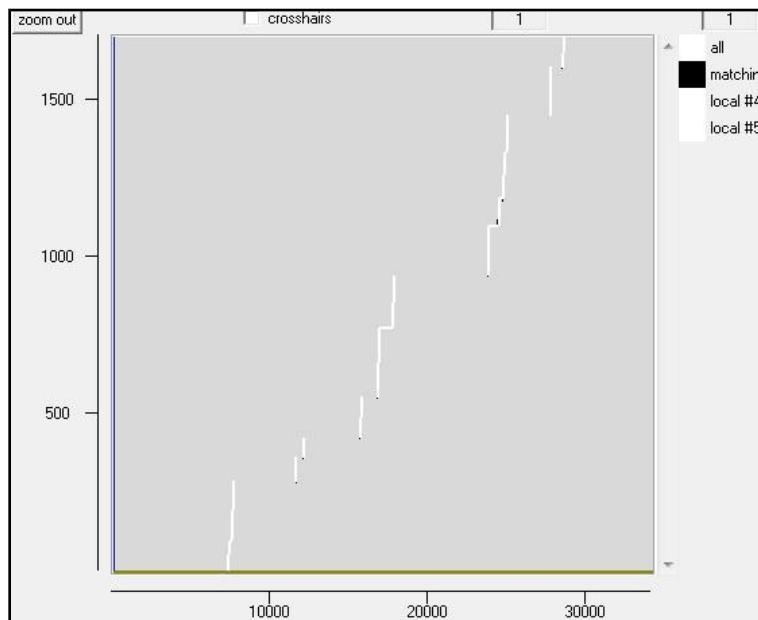
⁸⁴ I.e. report the best matching reaction and ignore any others, however deserving they might be? This has always seemed an odd default to me.

It really is very good practice to save the parameters also, as you did for the global alignments.

From spin's **Comparison** menu, select again **Local alignment**. Clearly, there is more than 1 meaningful local alignment. To see more, **spin** offers two options.

You could guess the **number of alignments** value. However, this is not trivial. You know the number of exons (and so the number of ungapped alignments expected) with some certainty by now, but this does not necessarily correspond to the expected number of local alignments. **spin** will combine close exons into single alignments if gap penalties are low enough. **spin** assumes that your choice of **number of alignments** is exactly correct. Too low and you will miss real alignments. Too high and **spin** will show alignments of ever increasing fantasy.

It is normally better, therefore, to specify the alignments you wish **spin** to display by providing a quality cut off rather than a volume cut off. To do this, turn on the **alignments above score** option. Use the default value of **20**.



It is not obvious how one might choose a sensible value. In such circumstances, the "lazy" option of just accepting the default is fine. Maybe someone sensible chose it? If not, one can always iterate to a value that works. I.e. if you would like more alignments, lower the value and try again. Too many? raise it. Repeat until the program agrees with what you wished to be correct in the first place. Is not science wonderful? With hope in your heart, click **OK**.

Looking at the graphic, I would say we got lucky this time⁸⁶. There is a local alignment that covers every exon identified by the dotplot and no extra results requiring explanation.

Take a look at the textual output. Save your results in a text file called **local_results02.txt** (Right click in **spin's Output window** and select **Output to disk**). Scan your results to find the exons. You should see that all have been correctly aligned.

Why do you suppose your aligned exons are not presented in the correct positional order?

[Further features of Spin](#)



[ORF Identification and Translation](#)



⁸⁶ If you wish to be meticulously honest. You should **Hide** the graphic of your first **Local alignment** (right click its configuration box, choose **Hide**). Not that it will change anything as you will have found exactly the same alignment the second time round – along with the others.

Searching for sequence similarities in databases.

Without doubt, the most popular way to investigate a sequence has always been to compare it with one of the sequence databases accessible from many sites all over the world. When sequences databases were more sparsely populated than now, the objective was to search hopefully, not always with success, for any convincingly similar sequence. When such a match was available, it could be supposed that known properties of the “similar” database sequence might provide insight to the properties of the query sequence. Now, the databases are full of sequences representative of most interesting conditions. Similarity searches are conducted in the expectation of finding many close “hits” for almost any sequence. It is also true that far fewer database searches are conducted in complete ignorance of what the query sequence might be.

For the purposes of this exercise, we will take the genomic DNA sequence extracted from **Ensembl** and conduct two searches that will be analogous to those run as part of the **Ensembl** pipeline. Our results should confirm that already discovered using the **Ensembl** browser.

blast is not the only sequence database searching program available, but it is the most popular by a very long way. **blast** searches are offered in many forms by many servers all over the world, but the most comprehensive and reliable service has to be that offered by the **NCBI**.

Go to the **NCBI** homepage at:

<http://ncbi.nlm.nih.gov>

Select the **BLAST** option (from the **Popular Resources** list). In the **Basic BLAST** section, select **nucleotide blast**. Use the **Enter Query Sequence Browse** (or **Choose File**) button to upload file **pax6_genomic.fasta**.

For results like those used by **Ensembl** to predict **PAX6** transcripts, you must compare your genomic sequence to a reliable set of human mRNA/cDNA (or similar) sequences.

In the **Choose Search Set** section, set the **Database** to **Reference RNA sequences (refseq_rna)**. You are now able to specify an **Organism**, choose **Human**. Note that the default **Program Selection** is **Highly similar sequences (megablast⁸⁷)**, which seems appropriate here.

Click on the **Algorithm Parameters** button. The defaults are fine here, but before you set your search going, try

changing the **Program Selection** and observing the effects on the **Algorithm Parameters**. You will see that the default parameter settings are identical for the two slower more sensitive **Program Selections**. There are differences for **megablast**, where speed is of the essence and sensitivity can be sacrificed.

A smaller **Word size** involves more work but increases sensitivity. For **megablast** it is **28** otherwise it is **11**.

Gapped alignment is very time consuming and hardly considered by **megablast**. **Gap costs** and carefully correspondent **Match/Mismatch scores** are only a real issue for the two more sensitive **Program Selections**.

Filtering and Masking matches with organism specific repeats and/or low complexity regions takes

time, and so only avoiding **Low complexity regions⁸⁸** is on by default for all **Program Selections**.

⁸⁷ **megablast** is a less sensitive but even faster version of **blast** only suitable when, as now, almost identical matches are sought.

⁸⁸ This filter avoids finding “hits” supported only by matches in regions not specific to the query. For example, a polyA tail cannot help to identify a specific mRNA as it is present in all mRNAs. The use of this filter will be evident when we look at the **blast** output.

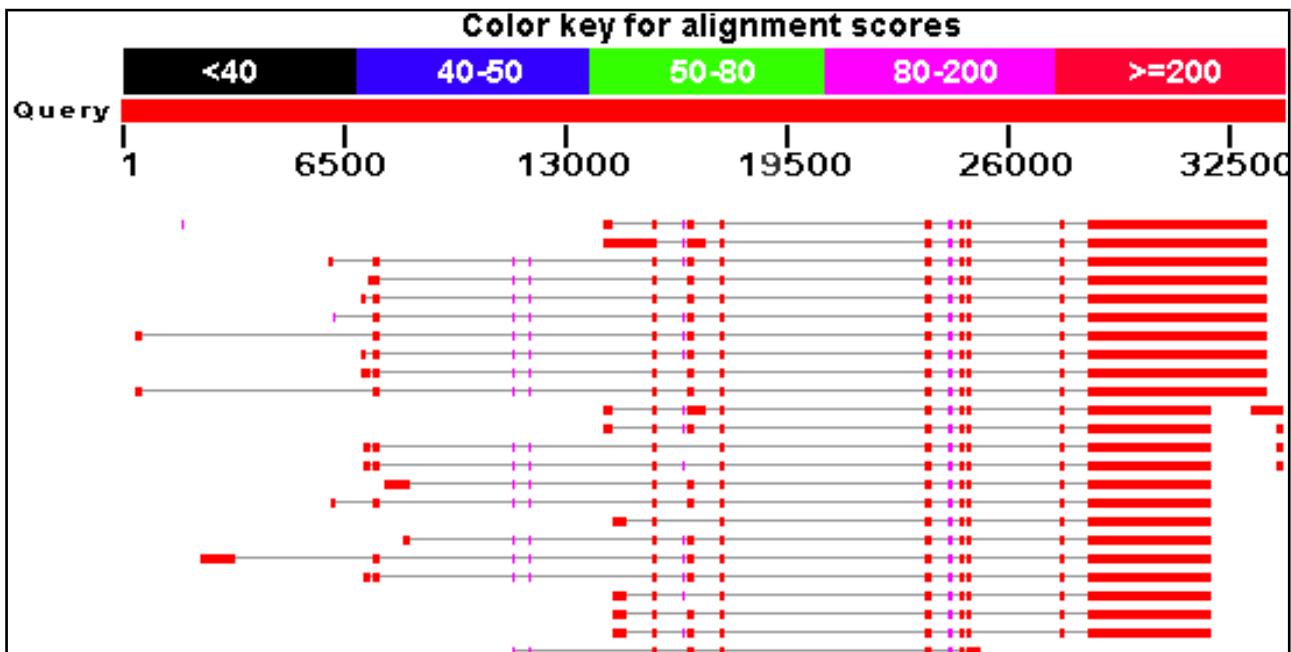
When **discontinuous megablast** is selected, an extra options section appears. Discussing how this flavour of **blast** works is a little beyond the scope of these notes, but briefly. Unlike the other **Program Selections**, **discontinuous megablast** does not just look for exactly matching “words” of given size as a first step towards identifying matching regions between sequences. It looks for a pattern of matching bases within a word. For example, the default choice assumes your query is **coding** and looks for **11** matching bases within a word of **18**. Approximately, every third base is allowed not to match. Biologically, this can be justified as allowing for third codon position wobble. For more detail, use the appropriate button. Notice there are buttons by every parameter selection. Try one or two. In the process, discover:

[When would Mask lower case letters be a useful thing to do?](#)

Automatically adjust parameters for short input sequences is independent of **Program selection**, and so remains unaltered.

[Which parameters would blast need to automatically adjust to cater for short input sequences \(such as primers being tested for uniqueness\), and why?](#)

Finally, ensure all the defaults are back in place⁸⁹ and the **megablast** is the **Program Selection**, ask **blast** to **Show results in a new window** and then click on the **BLAST** button. Impressively swiftly, you will have results. At the top of which will be a graphical overview.



This graphic implies that there are **24** full length matches between your genomic sequence and mRNAs in **RefSeq**. The **RefSeq** entries had to be “gapped” in order to compensate for the introns that are represented in the genomic sequence but removed from the mRNA sequences. The **red blocks** therefore represent very closely matching (**>=200** brownie points) exons, the lines joining the **red blocks** represent introns that have been spliced out. All **24** hits match reasonably uniformly except for the first few exons, implying variation in the **5' UTR**.

[Why do you suppose that a few of the exons do not achieve the maximum score?](#)

[Explain why one exon in the reasonably consistent region, does not appear in all of the transcript matches?](#)

RefSeq has acquired a number of new human **PAX6** transcripts lately. There now appear to be **11** high quality **NM_** entries. The last time I updated these notes (very recently!), there were but the **7** reported by **GeneCards** and implied by **Ensembl**. This suggests that **GeneCards** has not been updated and **Ensembl** has not recomputed its gene predictions since the **4** new **NM_** mRNAs were added to **RefSeq**. I expect they will all catch up with each other, and I will have to rewrite my notes, very soon. **blast** still detects just **13 XM_ PREDICTED** transcripts, as reported by **GeneCards**. It is reasonably safe to assume that **RefSeq** has recently found another **4** good quality human **PAX6**

⁸⁹ If you have any non-default settings, they should be highlighted in yellow. This works for nearly all parameters!

mRNA that will eventually be reported by **GeneCards** and will probably increase the number of **PAX6** transcripts predicted by **Ensembl**.

If you hover over the graphical hits, their origin will be displayed above the graphic⁹⁰. The facts are:

The top **10** and the bottom **1** full length hits are of the best quality (i.e. **NM_** entries with good supporting evidence). **11** in all.

From the **11th** full length hit, there are **13** entries all labelled “**PREDICTED**”. We have already concluded that **Ensembl** is clever enough not to rely on **PREDICTED RefSeq** entries alone to justify an **Ensembl** transcript prediction. **GeneCards** does count them as sufficient to indicate **RefSeq** transcript predictions however.

There are **4** small hits to the extreme right of the graphics at the same level as the top **4 PREDICTED** hits. These are the ends of **mRNAs** for the **ELP4** gene and are exactly where you should expect them to be given previous discussion. Reject these contemptuously, they do not pertain to our investigation of **PAX6**.

The tiny smudge match to the left of the top hit is “**uncharacterized**” and fails to fit in with my story, so I ignore it!

So, this **blast** search suggests the existence of **24 PAX6** transcripts supported by **RefSeq** data, as will be reported by **GenCards** once it is updated. Also, the results are consistent with the information discovered in **Ensembl**.

Move down a trifle and you will find a simple list of the **29** matches represented in the graphic.

| | Description | Max score | Total score | Query cover | E value | Ident | Accession |
|--------------------------|--|-----------|-------------|-------------|---------|-------|--------------------------------|
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 11, mRNA | 9659 | 12484 | 19% | 0.0 | 100% | NM_001310161.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 10, mRNA | 9659 | 15161 | 24% | 0.0 | 100% | NM_001310160.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 8, mRNA | 9659 | 12929 | 20% | 0.0 | 100% | NM_001310158.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 7, mRNA | 9659 | 12729 | 20% | 0.0 | 100% | NM_001258465.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 6, mRNA | 9659 | 12761 | 20% | 0.0 | 100% | NM_001258464.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 5, mRNA | 9659 | 12737 | 20% | 0.0 | 100% | NM_001258463.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 4, mRNA | 9659 | 12862 | 20% | 0.0 | 100% | NM_001258462.1 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 2, mRNA | 9659 | 12833 | 20% | 0.0 | 100% | NM_001604.5 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 1, mRNA | 9659 | 12942 | 20% | 0.0 | 100% | NM_000280.4 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 3, mRNA | 9659 | 12791 | 20% | 0.0 | 100% | NM_001127612.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X13, mRNA | 6613 | 10063 | 15% | 0.0 | 100% | XM_005252958.3 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X12, mRNA | 6613 | 9439 | 14% | 0.0 | 100% | XM_011520153.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X11, mRNA | 6613 | 9329 | 14% | 0.0 | 100% | XM_006718246.2 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X10, mRNA | 6613 | 9410 | 14% | 0.0 | 100% | XM_011520152.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X9, mRNA | 6613 | 10507 | 16% | 0.0 | 100% | XM_005252956.3 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X8, mRNA | 6613 | 9783 | 15% | 0.0 | 100% | XM_005252955.3 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X7, mRNA | 6613 | 9091 | 14% | 0.0 | 100% | XM_011520151.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X6, mRNA | 6613 | 9637 | 15% | 0.0 | 100% | XM_011520150.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X5, mRNA | 6613 | 11324 | 17% | 0.0 | 100% | XM_011520149.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X4, mRNA | 6613 | 9814 | 15% | 0.0 | 100% | XM_005252954.3 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X3, mRNA | 6613 | 9172 | 14% | 0.0 | 100% | XM_011520148.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X2, mRNA | 6613 | 9502 | 15% | 0.0 | 100% | XM_011520147.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X1, mRNA | 6613 | 9576 | 15% | 0.0 | 100% | XM_011520146.1 |
| <input type="checkbox"/> | PREDICTED: Homo sapiens elongator acetyltransferase complex subunit 4 (ELP4), transcript variant 1, mRNA | 1775 | 1775 | 2% | 0.0 | 100% | XM_005252865.2 |
| <input type="checkbox"/> | Homo sapiens paired box 6 (PAX6), transcript variant 9, mRNA | 647 | 2630 | 4% | 0.0 | 100% | NM_001310159.1 |
| <input type="checkbox"/> | Homo sapiens elongator acetyltransferase complex subunit 4 (ELP4), transcript variant 3_r | 433 | 433 | 0% | 6e-118 | 100% | NM_001288726.1 |
| <input type="checkbox"/> | Homo sapiens elongator acetyltransferase complex subunit 4 (ELP4), transcript variant 2_r | 433 | 433 | 0% | 6e-118 | 100% | NM_001288725.1 |
| <input type="checkbox"/> | Homo sapiens elongator acetyltransferase complex subunit 4 (ELP4), transcript variant 1_r | 433 | 433 | 0% | 6e-118 | 100% | NM_019040.4 |
| <input type="checkbox"/> | Homo sapiens uncharacterized LOC440034 (DKFZp686K1684), long non-coding RNA | 141 | 141 | 0% | 4e-30 | 100% | NR_033971.1 |

Why were you not surprised to discover **24 PAX6** transcripts in **Refseq** matching this sequence? _____

Which of the **Refseq PAX6** transcripts corresponds to **isoform 5a**? _____

Moving further down the results you will come to the alignments between **pax6-genomic** and the matching database entries. All similarity searches use local alignment strategies⁹¹, so you should not be surprised to see a number of alignments for each “hit” in the list. Here we have a genomic query sequence aligned with entries from an mRNA

90 Or you could just read the textual list that follows the graphic if you wish to insist on the simplistic.

91 To use a global approach would be to imply that you were only interested in database entries that matched your query sequence from end to end. Generally, this is not true. You would usually be interested in a database sequence that was similar over any significant region.

database. The expectation is therefore to find an alignment corresponding to each exon. The alignments are ordered by quality, though you are provided with a **Sort by:** menu to alter the order to taste⁹².

Look at the first alignment for the best matching **PAX6** transcript. It is the alignment of the very last exon of a **RefSeq** transcript with the end of the gene you exported from **Ensembl**. The **500** base pairs of 3' flanking sequence added on to the **Ensembl** sequence for “good measure”, is not part of the alignment (as would be expected).

Notice the lower case string of 'a's. The case indicates that they were ignored (**filtered**) as a **Low complexity region** whilst **megablast** was looking for identically matching words that might suggest matching regions⁹³. By themselves, the 'a's are not sufficient evidence that a biological match exists. Only as the surrounding sequence is also compellingly similar, can it be assumed that such a match does exist. The 'a's are replaced (lower case to indicate they were filtered) when the final alignment is computed. If you look a little further down the same alignment, you will see several other runs of 'a's and 't's for which the same explanation applies.

| | Score
9659 bits(5230) | Expect
0.0 | Identities
5230/5230(100%) | Gaps
0/5230(0%) | Strand
Plus/Plus |
|-------|---------------------------------|---|--------------------------------------|---------------------------|----------------------------|
| Query | 28441 | AGGACTCATTTCCCTGGTGTCAAGTTCCAGTTCAAGTTCCCGGAAGTGAACCTGATAT | | | 28500 |
| Sbjct | 1500 | AGGACTCATTTCCCTGGTGTCAAGTTCCAGTTCAAGTTCCCGGAAGTGAACCTGATAT | | | 1559 |
| Query | 28501 | GTCTCAAATACTGGCCAAGATTACAGTaaaaaaaaaaaaaaaaaaaaaaGGAAAGGAAAT | | | 28560 |
| Sbjct | 1560 | GTCTCAAATACTGGCCAAGATTACAGTaaaaaaaaaaaaaaaaaaaaaaAGGAAAGGAAAT | | | 1619 |
| Query | 28561 | ATTGTGTTAATTCACTCAGTGACTATGGGGACACAACAGTTGAGCTTCAGGAAAGAAAAG | | | 28620 |
| Sbjct | 1620 | ATTGTGTTAATTCACTCAGTGACTATGGGGACACAACAGTTGAGCTTCAGGAAAGAAAAG | | | 1679 |

⁹³ The mRNA in the file **pax6_cdna.fasta** ends at this polyA region. I wonder about the long 3' UTR suggested by the **RefSeq** entries?

Now use a version of **blast** (called **blastx**) to compare your genomic sequence with protein databases. **blastx** will translate a query sequence in all six reading frames and compare each translation with a protein sequence database. Thus, in a similar fashion to that employed by the **Ensembl** pipeline, protein coding regions of the genomic DNA can be identified. For clarity, we will use only the well annotated human proteins of the **SwissProt** section of **Uniprot**. First go to the home of **blast** at:

<http://blast.ncbi.nlm.nih.gov/Blast.cgi>

In the **Basic BLAST** section, select **blastx**. Use the **Enter Query Sequence Browse (or Choose File)** button to **upload file pax6_genomic.fasta**.

In the **Choose Search Set** section, set the **Database to UniProtKB/Swiss-prot prot(swissprot)**.

Specify **Organism as Human**.

Take a look at the **Algorithm parameters**⁹⁴.

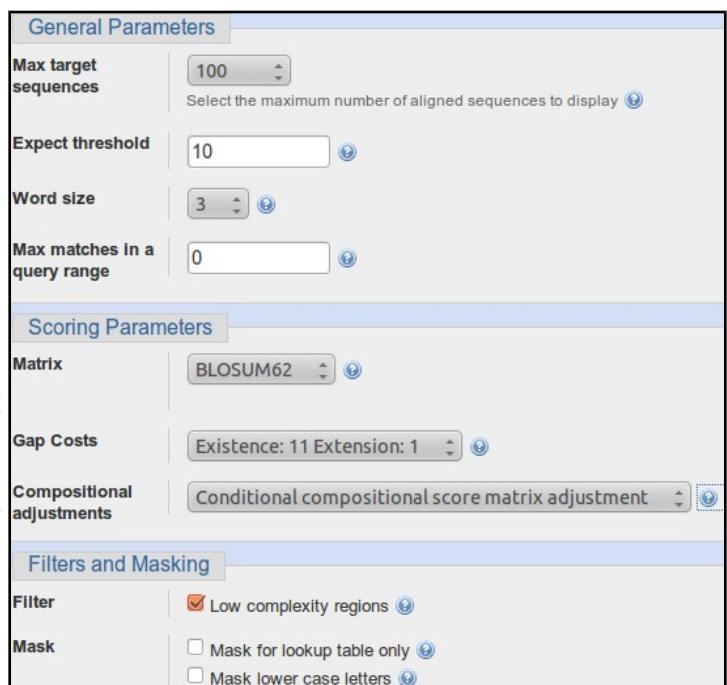
Note that the **Word size** choice is **3** or **2** with a default of **3**.

The default scoring matrix is **BLOSUM62**, but choices from both the **BLOSUM** and **PAM** families are offered.

Low complexity regions will be filtered by default.

The **Max matches in a query range** is worth knowing about. Use the appropriate  button to discover more.

In what circumstances would you imagine that the **Max matches in a query range** parameter might be set to something other than its default value of **0**? _____



General Parameters

Max target sequences: 100
Select the maximum number of aligned sequences to display 

Expect threshold: 10 

Word size: 3 

Max matches in a query range: 0 

Scoring Parameters

Matrix: BLOSUM62 

Gap Costs: Existence: 11 Extension: 1 

Compositional adjustments: Conditional compositional score matrix adjustment 

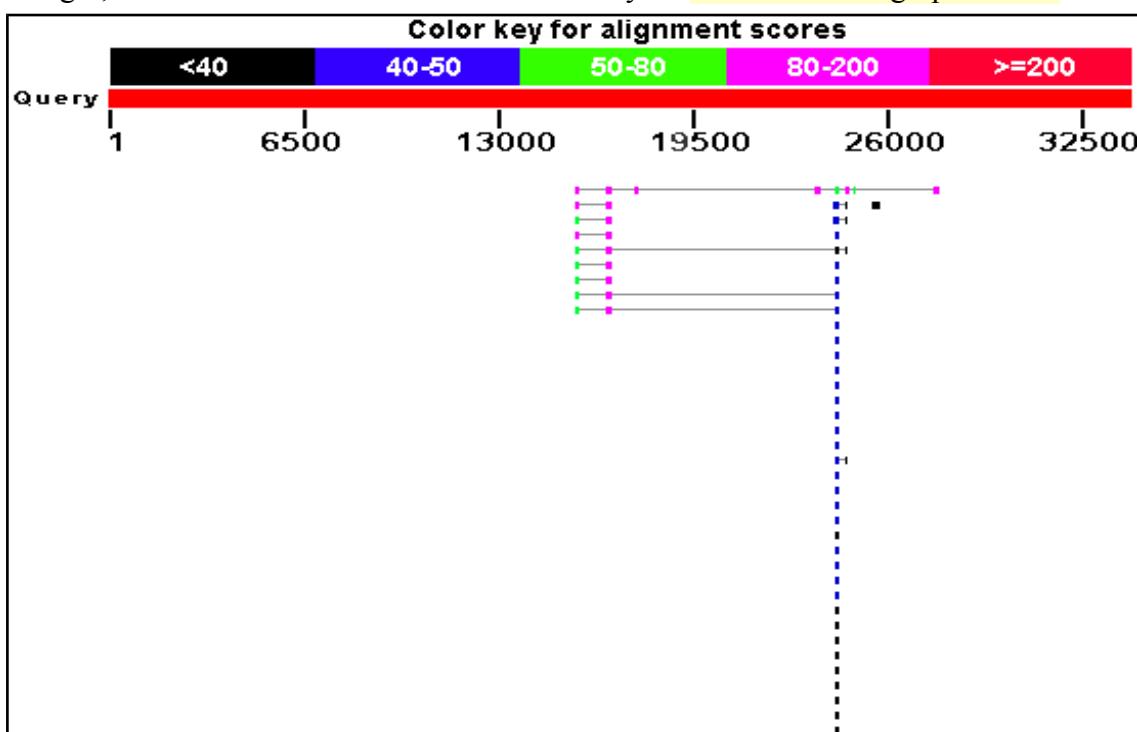
Filters and Masking

Filter: Low complexity regions  

Mask: Mask for lookup table only  
Mask lower case letters  

Change nothing other than to ask **blast** to **Show results in a new window**. and click the **BLAST** button.

After minimal thought, **blastx** will thrust its conclusions before you. Hover over the graphical hits for identification.



What are the **9** stronger matches around base position **16,000**? _____

Why would you expect exactly **9** matches around this point? _____

94 Here I will assume we have talked about these parameter and you are reasonably well informed of the issues.

What do you make of the plethora of matches around **24,000?**

Move down to the textual list of the matches. Hopefully as you fully expected you will find the expected number of **Paired box** matches at the top of the list followed by many many **Homeobox** matches.

| | Description | Max score | Total score | Query cover | E value | Ident | Accession |
|--------------------------|---|-----------|-------------|-------------|---------|-------|-----------|
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-6; AltName: Full=Aniridia type II protein; AltName: Full=Oculorhom | 160 | 767 | 3% | 2e-40 | 97% | P26367.2 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-2 [Homo sapiens] | 131 | 214 | 1% | 8e-31 | 74% | Q02962.4 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-8 [Homo sapiens] | 131 | 208 | 1% | 1e-30 | 76% | Q06710.2 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-5; AltName: Full=B-cell-specific transcription factor; Short=BSAP [H | 128 | 211 | 1% | 6e-30 | 74% | Q02548.1 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-4 [Homo sapiens] | 117 | 258 | 1% | 2e-26 | 67% | O43316.1 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-9 [Homo sapiens] | 112 | 179 | 1% | 5e-25 | 69% | P55771.3 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-1; AltName: Full=HuP48 [Homo sapiens] | 111 | 177 | 1% | 4e-24 | 69% | P15863.4 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-3; AltName: Full=HuP2 [Homo sapiens] | 107 | 219 | 1% | 7e-23 | 65% | P23760.2 |
| <input type="checkbox"/> | RecName: Full=Paired box protein Pax-7; AltName: Full=HuP1 [Homo sapiens] | 105 | 217 | 1% | 5e-22 | 68% | P23759.3 |
| <input type="checkbox"/> | RecName: Full=Retinal homeobox protein Rx; AltName: Full=Retina and anterior neural fold homeobox pr | 48.9 | 84.7 | 0% | 1e-04 | 46% | Q9Y2V3.2 |
| <input type="checkbox"/> | RecName: Full=Retina and anterior neural fold homeobox protein 2; AltName: Full=Q50-type retinal home | 46.2 | 80.5 | 0% | 2e-04 | 48% | Q96IS3.1 |
| <input type="checkbox"/> | RecName: Full=Homeobox protein aristaless-like 4 [Homo sapiens] | 47.4 | 47.4 | 0% | 4e-04 | 68% | Q9H161.2 |
| <input type="checkbox"/> | RecName: Full=Paired mesoderm homeobox protein 1; AltName: Full=Homeobox protein PHOX1; AltNam | 45.8 | 45.8 | 0% | 7e-04 | 68% | P54821.2 |
| <input type="checkbox"/> | RecName: Full=Paired mesoderm homeobox protein 2; AltName: Full=Paired-related homeobox protein 2; | 45.8 | 45.8 | 0% | 7e-04 | 68% | Q99811.2 |
| <input type="checkbox"/> | RecName: Full=Dorsal root ganglia homeobox protein; AltName: Full=Paired-related homeobox protein-li | 45.8 | 45.8 | 0% | 8e-04 | 71% | A6NNA5.1 |

Why do you suppose the **Paired box** matches precede the **Homeobox** matches?

How do you suppose the **Max matches in a query range** parameter might be of value if this order was reversed?

Take a look at the alignments. You will see many places where regions have been filtered as non-informative. I suggest the one illustrated was filtered because it would match anywhere that was sufficiently **Serine** rich.

| Score | Expect | Method | Identities | Positives | Gaps | Frame |
|----------------|---|------------------------------|------------|------------|----------|-------|
| 81.3 bits(199) | 5e-29 | Compositional matrix adjust. | 51/52(98%) | 51/52(98%) | 0/52(0%) | +3 |
| Query 24654 | FQWFSNRRAKWRREEKLRNQRRQASN
tpshipisssfsts | VYQPIPQPTTP | | 24809 | | |
| Sbjct 254 | IQWFSNRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTS
VYQPIPQPTTP | | | 305 | | |

How does this “non-informative” region match expectations suggested by **Prosite** and the **Feature table of Uniprot** for **PAX6_HUMAN**?

Primer Design

To determine the presence or absence of the mutation we have detected, a test based on restriction maps could be employed. This approach is investigated in one of the supplementary exercises at the end of this book. In that extra exercise, it is shown there is more than one restriction enzyme whose cut site is dependant upon the mutation. With a little more work (with the same programs), we could easily ascertain exact restriction fragment sizes expected for selected enzyme(s) with the mutation and without it. As long as the differences were sufficiently unsubtle, a **Restriction Fragment Length Polymorphism (RFLP)** test could be designed.

For a variety of reasons, including the ready availability and low cost of sequencing, this is typically not the preferred way to proceed. It is normally preferable to use PCR to isolate the region around the mutation and sequence all individuals under examination. To do this, the first step would be to design suitable PCR primers. One program, in many different forms, is almost exclusively used for this purpose. The program is **primer3**. It is free and can be downloaded and run under linux and windows (at least). It is available as part of the **EMBOSS** package (**eprimer3**) and from a number of websites, including at the **Massachusetts Institute of Technology (MIT)**⁹⁵:

<http://frodo.wi.mit.edu/>

This site is popular with many users offering complete control over the various options offered by **primer3**.

Another excellent **primer3** web interface (linked from the **MIT** site) developed in the Netherlands is available at:

<http://www.bioinformatics.nl/cgi-bin/primer3plus/primer3plus.cgi>

The site incorporates access to a **blast** search to check the uniqueness of the selected primers (important if unwanted PCR products are to be avoided).

Mostly because of its completely seamless inclusion of a **blast** search to compare potential primers with appropriate sequence collections, I suggest we here use **primer3** as implemented at the **NCBI**, even though it offers less than complete control over the execution of **primer3** itself. Go to:

<http://www.ncbi.nlm.nih.gov>

Click on the **BLAST** option. Select **Primer-BLAST** from the **Specialized BLAST** section.

Upload your genomic **PAX6** sequence using the **Browse** (or **Choose File**) button for the **PCR Template**.

You have established that the mutation of greatest interest is the

G/C substitution at position **15714** of the genomic sequence copied from **Ensembl**. It is logical therefore to specify that this feature be included in the PCR product not too near either end. Accordingly, request the **Forward primer** to be chosen **From** the region starting at base pair **15000** and continuing **To** base pair **15700**. Set the range for the **Reverse primer** to be **From 15800** and **To 16500**.

The default **PCR product size** is specified in the **Primer Parameters** section as between **70** and **1000** base pairs. This seems fine.

I would not presume to advise you on the melting temperatures that were most suitable⁹⁶. For this exercise, the defaults work splendidly.

By default, **primer-BLAST** will report the best **10** primer pairs it can find (**# of primers to return**). This is plenty for the exercise.

Do you think **10** primer pair suggestions is sufficient? If not, what number would you choose? _____

95 The **MIT** now offer a new version of **primer3** (version **0.4.0**, soon **primer4** maybe?). Its URL is: <http://bioinfo.ut.ee/primer3-0.4.0/>. I have yet to investigate this version fully.

96 My policy has been to not discuss parameters that pertain to the experimental conditions. I think now that there are some such parameters that do need a little discussion. I will include this in future versions of these notes. In the mean time, I recommend going to the **MIT** site (or the **Wageningen** site) and making use of the very readable explanations linked from every parameter. The full **primer3** manual can be found here.

In addition to running primer3 to suggest primers, **Primer-BLAST** checks against the possibility of unwanted PCR products by comparing potential primers against an appropriate sequence database with **blast**.

In the **Primer Pair Specificity Checking Parameters** section, set the **Database** selection to **Genome (reference assembly from selected organisms)**. Leave the **Organism** set as **Homo sapiens**.

You thus request each potential pair of PCR primers to be compared to the entire human genome.

Unintended products, similar in size to the intended product, can so be identified.

The ideal conclusion is “just one product will be produced, on chromosome 11, in the region of the **PAX6** gene”.

Primer Pair Specificity Checking Parameters

Specificity check: Enable search for primer pairs specific to the intended PCR template [?](#)

Search mode: **Automatic** [?](#)

Database: **Genome (reference assembly from selected organisms)** [?](#)

Organism: **Homo sapiens**
Enter an organism name, taxonomy id or select from the suggestion list as you type. [?](#)
[Add more organisms](#)

Exclusion (optional): Exclude predicted Refseq transcripts (accession with XM, XR prefix) Exclude uncultured/environmental sample sequences [?](#)

Entrez query (optional):

Primer specificity stringency: Primer must have at least **2** total mismatches to unintended targets, including at least **2** mismatches within the last **5** bps at the 3' end. [?](#)
Ignore targets that have **6** or more mismatches to the primer. [?](#)

Max target size: **4000** [Note the parameter change](#) [?](#)

Splice variant handling: Allow primer to amplify mRNA splice variants (requires refseq mRNA sequence as PCR template input) [?](#)

Use the appropriate [?](#) button to discover the purpose of the **Max target size** parameter.

This is a new parameter replacing a very different parameter, the purpose of which was somewhat less obvious. The reason for the **Max target size** parameter is surely pretty transparent, so maybe there is now less requirement to wake up its [?](#) button? For the present, the maximum size of any proposed PCR product, in this instance, is **1,000** base pairs (the form default). So the greatest size of an unwanted product that might be a problem (the **Max target size**) must be small enough to potentially be mistaken for a real product of **1,000** base pairs. **4,000** base pairs seems a bit cautious to me? However, unless you feel strongly about the matter, accept the default value of **4000**.

What value would you choose here if you were looking for uncluttered results?

Before setting **primer-BLAST** going, click on the **Advanced parameters** button. Not really so **Advanced**? More **Avoidable** by those in a hurry. At the top are the **Primer Pair Specificity Checking Parameters** that control the way that **blast** is run. Note the [?](#) buttons offering explanation.

Note the very high default **Blast expect (E) value**, suggesting you will be interested in matches with your primers that might occur up to **30000** times by chance! This does make sense as the primers will be very short and so many good, even exact, “chance” matches might be expected against a large database.

Comment upon the small default value for the **Blast word size**?

Primer Pair Specificity Checking Parameters

Max number of Blast target sequences: **50000** [?](#)

Blast expect (E) value: **30000** [?](#)

Blast word size: **7** [?](#)

Max primer pairs to screen: **500** [?](#)

Max targets to show (for designing new primers): **20** [?](#)

Max targets to show (for pre-designed primers): **1000** [?](#)

Max targets per sequence: **100** [?](#)

Internal hybridization oligo parameters

Hybridization oligo: Pick internal hybridization oligo

| | Min | Opt | Max |
|-----------------------|-------------|-------------|-------------|
| Hyb Oligo Size | 18 | 20 | 27 |
| Hyb Oligo tm | 57.0 | 60.0 | 63.0 |
| Hyb Oligo GC% | 20.0 | 50 | 80.0 |

Note that you could get **primer-BLAST** to suggest an **Internal hybridisation oligo**, but decline the invitation this time.

Accept all the **Advanced parameters** as they are. Ask **primer-BLAST** to Show results in a new window.

Click on the **Get Primers** button.

After a few moments of deep thought, **primer-BLAST** will notice that the template sequence you are using is **highly similar** (identical in fact) to part of an entry in the database being searched. Hardly surprising if one was to think about it.

Input PCR template pax6-genomic sequence
Range 15000 - 16500

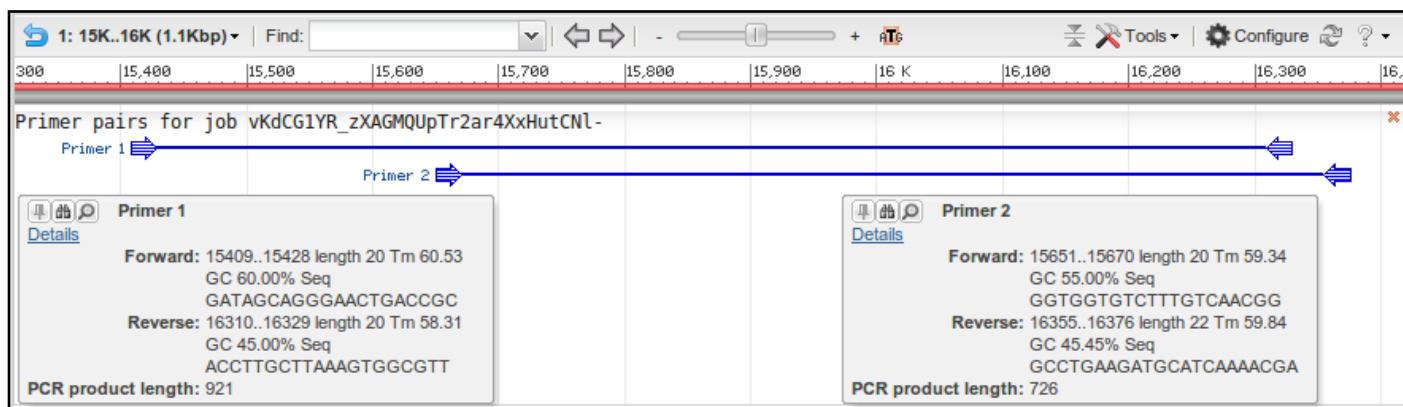
Your PCR template is highly similar to the following sequence(s) from the search database. To increase the chance of finding specific primers, please review the list below and select all sequences (within the given sequence ranges) that are intended or allowed targets.

| Select: All None Selected:1 | | Accession | Title | Identity | Alignment length | Seq. start | Seq. stop | Gene |
|-----------------------------|--|---|--|----------|------------------|------------|-----------|------|
| | | <input checked="" type="checkbox"/> NC_000011.10 | Homo sapiens chromosome 11, GRCh38.p2 Primary Assembly | 100% | 1501 | 31801962 | 31803462 | PAX6 |
| | | <input type="checkbox"/> Show results in a new window | | | | | | |
| | | <input type="button" value="Submit"/> | | | | | | |

You are invited to select all listed regions (just one this time) where matches with primers are likely to be the intended product. In this case, that is the whole list of one, so click on the **All** button.

Every pair of primers that **primer3** selects **must** match this region of **Chromosome 11** as it is precisely the region investigated by **primer3** in the first place. This process avoids **blast** reporting intended products as unintended products. Finally, all is ready, so ask to **Show results in a new window** and then click on the **Submit** button.

Once you have revelled in the opportunity to twiddle the fingers and scratch the ear(s) whilst **primers3** and **blast** go merrily about their appointed tasks, you will receive your results. These should look disarmingly like mine if all has gone well, in **Summary** and in **Detail**.



| Primer pair 1 | | | | | | |
|--|-----------------------|-----------------------|--------|----------|-------|-------|
| | Sequence (5'->3') | Template strand | Length | Start | Stop | Tm |
| Forward primer | GATAGCAGGGAACGTGACCGC | Plus | 20 | 15409 | 15428 | 60.53 |
| Reverse primer | ACCTTGCTTAAAGTGGCGTT | Minus | 20 | 16310 | 16329 | 58.31 |
| Product length | 921 | | | | | |
| Products on Intended target | | | | | | |
| >NC_000011.10 Homo sapiens chromosome 11, GRCh38.p2 Primary Assembly | | | | | | |
| product length = 921 | | | | | | |
| Features associated with this product: | | | | | | |
| paired_box_protein_Pax-6_isoform_X6 | | | | | | |
| paired_box_protein_Pax-6_isoform_X1 | | | | | | |
| Forward primer | 1 | GATAGCAGGGAACGTGACCGC | 20 | | | |
| Template | 31803053 | | | 31803034 | | |
| Reverse primer | 1 | ACCTTGCTTAAAGTGGCGTT | 20 | | | |
| Template | 31802133 | | | 31802152 | | |

| Primer pair 2 | | | | | | |
|--|------------------------|------------------------|--------|-------|----------|-------|
| | Sequence (5'->3') | Template strand | Length | Start | Stop | Tm |
| Forward primer | GGTGGTGTCTTGTCAACGG | Plus | 20 | 15651 | 15670 | 59.34 |
| Reverse primer | GCCTGAAGATGCATCAAAACGA | Minus | 22 | 16376 | 16395 | 59.84 |
| Product length | 726 | | | | | |
| Products on Intended target | | | | | | |
| >NC_000011.10 Homo sapiens chromosome 11, GRCh38.p2 Primary Assembly | | | | | | |
| product length = 726 | | | | | | |
| Features associated with this product: | | | | | | |
| paired_box_protein_Pax-6_isoform_X6 | | | | | | |
| paired_box_protein_Pax-6_isoform_X1 | | | | | | |
| Forward primer | 1 | GGTGGTGTCTTGTCAACGG | 20 | | | |
| Template | 31802811 | | | | 31802792 | |
| Reverse primer | 1 | GCCTGAAGATGCATCAAAACGA | 22 | | | |
| Template | 31802086 | | | | 31802107 | |

Just **two** solutions met the default criteria for success used by **primer3**. Up to **10** were permitted⁹⁷. Hovering over the graphical results will bring forth textual summaries. Try it. Note the rather ugly job identification! Clearly, the poetry generated for your results is extremely unlikely to be the same as illustrated.

Neither of your two suggested primer pairs should be associated with any unintended products, even with the very generous suggestion that products **4000** bases long should be considered a potential problem⁹⁸.

⁹⁷ Which rather makes mock of all the deep thought employed deciding upon the most sensible maximum number of predictions to be reported.

⁹⁸ This was not true until very recently. **Primer-BLAST** reported many more primer pair suggestions and quite a few unintended products for each. The previous parameter restriction the length of unintended products was somewhat more generous.

As well as suggesting primers for PCR (or other purposes) and (optionally) suggesting hybridisation oligos, **primer-BLAST** can be used to evaluate user-selected primers. Earlier, you saved a pair of primer sequences associated with **PAX6** when searching the nucleotide databases at the **NCBI**. It would be interesting to discover the product these might produce. To do this you need an unsullied **Primer-BLAST** page. Go again to:

<http://www.ncbi.nlm.nih.gov>

Click on the **BLAST** option. Select **Primer-BLAST** from the **Specialized BLAST** section. Upload your genomic **PAX6** genomic sequence using the **Browse (or Choose File)** button for the **PCR Template**.

Open up the file you made containing the primers from **GenBank (pax6_primers.fasta)** in a text editor.

Copy and Paste the two primer sequences into the **Use my own forward primer** and **Use my own reverse primer** boxes as appropriate.

In the **Primer Pair Specificity Checking Parameters** section, set the **Database** selection to **Genome (reference assembly from selected organisms)**.

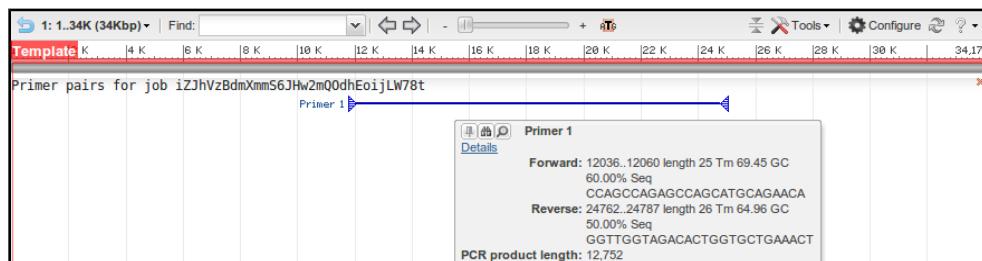
Leave the **Organism** as **Homo sapiens**.

Raise the **Max target size** parameter from **4000** to **20000**. You will be checking for enormous unintended products with this run of **Primer-BLAST**. The reasons for this will become apparent soon.

Get Primers

Show results in a new window Use new graphic view

Ask primer-BLAST to Show results in a new window.



Click on the **Get Primers** button.

After a short thrill filled pause, you will receive a result that should again looks more that a trifle like mine.

On the face of it, a fine match, an excellent result. Even the single **potentially unintended product** reported is actually the **intended product**. For some reason that is not immediately apparent to me, **Primer-BLAST** does not protect against discovering intended products when looking for unintended ones when examining specific primers⁹⁹?

Success! However, applying a small measure of sober reflection, one has to wonder at a PCR product of **12,752** base pairs? I suspect that to be just a tad on the boastful side of probable¹⁰⁰? Clearly, **primer-BLAST** is convinced, but mayhap a look at the references

that came with these primer sequences would be advised before accepting this result at face value.

99 I have asked the guys at NCBI to explain. No full answer as yet, further prodding required.

100 Apparently, such a PCR product is possible! However, above 5,000 base pairs would be slow, require very close attention and be prone to errors.

Unfortunately, the only paper referenced does not explain what might be going on particularly clearly. However, there is a hint that the primers you saved were designed for use with mRNA/cDNA data. Therefore it might be interesting to run **primer-BLAST** one last time with **pax6_cdna.fasta** as the **PCR Template**.

Simply move back to your last **primer-BLAST** launch page. This time, load **pax6_cdna.fasta** as the **PCR Template**.

In the **Primer Pair Specificity Checking Parameters** section, set the **Database** selection set to **Refseq mRNA** and leave the organism set to **Homo sapiens**.

Set the **Max target size** back to its default value of **4000**, you should expect much smaller mRNA products this time, so no need for extending this maximum beyond **4000**.

These selections suppose that the design of PCR product was for selection from a library of all human cDNAs.

As ever, ask **primer-BLAST** to Show results in a new window.

Click on the **Get Primers** button.

Get Primers

Show results in a new window Use new graphic view

| Primer pair 1 | | | | | |
|-------------------------|----------------------------|-----------------|--------|-------|------|
| | Sequence (5'->3') | Template strand | Length | Start | Stop |
| Forward primer | CCAGCCAGAGCCAGCATGCAGAACAA | Plus | 25 | 403 | 427 |
| Reverse primer | GGTTGGTAGACACTGGTGTGAACT | Minus | 26 | 1310 | 1285 |
| Product length | 908 | | | | |
| Self 3' complementarity | 6.00 | | | | |
| Self 5' complementarity | 0.00 | | | | |

Products on potentially unintended templates

>[NM_001310159.1](#) Homo sapiens paired box 6 (PAX6), transcript variant 9, mRNA

```
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACAA 25
Template 114 ..... 138
```

Reverse primer 1 GGTTGGTAGACACTGGTGTGAACT 26
Template 1021 996

>[NM_001310158.1](#) Homo sapiens paired box 6 (PAX6), transcript variant 8, mRNA

```
product length = 950
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACAA 25
Template 496 ..... 520
```

Reverse primer 1 GGTTGGTAGACACTGGTGTGAACT 26
Template 1445 1420

>[XM_006718246.2](#) PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X11, mRNA

```
product length = 707
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACAA 25
Template 457 ..... 481
```

Reverse primer 1 GGTTGGTAGACACTGGTGTGAACT 26
Template 1163 1138

>[XM_011520152.1](#) PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X10, mRNA

```
product length = 749
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACAA 25
Template 457 ..... 481
```

Reverse primer 1 GGTTGGTAGACACTGGTGTGAACT 26
Template 1205 1180

>[XM_005282956.3](#) PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X9, mRNA

```
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACAA 25
Template 876 ..... 900
```

Reverse primer 1 GGTTGGTAGACACTGGTGTGAACT 26
Template 1783 1758

The result is a much more reasonable **Product length** of just **908** base pairs, reinforcing the theory that these primers were indeed designed for use with a cDNA library.

Before moving on, afford a quick glance at the report offered concerning possible unintended products. Here **primer-BLAST** warns against human mRNAs that might be cloned along with the intended target.

The first thing to note is that the intended target is not generated from a **RefSeq** mRNA. It comes from an mRNA taken from an **aniridia** patient directly. Therefore, there is no unintended product that we can ignore because it is really the intended product discovered by a different route, even though no filtering of the **RefSeq** database was undertaken.

All the unintended products could/would potentially be generated by the primers under investigation and have the potential to cause confusion. If you look down the list, you should conclude that the **16** unintended products come from **16** of the **24 RefSeq PAX6** transcripts first noted by **GeneCards¹⁰¹** and then confirmed later by **blast**.

101 Well, at least they will be noted by **GeneCards** as soon as they bring themselves up to date!

9 of the 11 NM_ good quality transcripts are detected. 7 of the 13 poorer quality XM_ “PREDICTED” transcripts are also present. So 16 of the 24 PAX6 transcript sequences in RefSeq were detected.

Why do you suppose **blast** did not pick up all the transcripts? _____

Note that the intended product is **908** base pairs long. Note that all the unintended products except two, near the top of the list are either **908** long or **950** long. A difference of **42**.

How would you tell quickly which isoform was represented by each mRNA listed here? _____

Some fairly redundant questions to finish this section. I think I have already answered them all. But maybe you might wish to differ?

Is the number of “**potentially unintended products**” as you would you expect, given the evidence from **GeneCards**, **Ensembl** and **blast**? _____

For all the “**potentially unintended products**”, the selected primers match exactly. Can you explain this? _____

The “**potentially unintended products**” are of different sizes. Can you explain the difference between the possible product lengths? _____

Are the numbers of “**potentially unintended products**” of each possible length consistent with your **blast** results? _____

```
>XM_005252953_3 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X8, mRNA
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 481 ..... 585
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1388 ..... 1363

>XM_011520150_1 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X6, mRNA
product length = 958
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 366 ..... 398
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1315 ..... 1298

>XM_011520149_1 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X5, mRNA
product length = 958
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 1275 ..... 1299
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 2224 ..... 2199

>XM_005252954_3 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X4, mRNA
product length = 958
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 457 ..... 481
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1406 ..... 1381

>NM_001258465_1 Homo sapiens paired box 6 (PAX6), transcript variant 7, mRNA
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 429 ..... 453
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1336 ..... 1311

>NM_001258464_1 Homo sapiens paired box 6 (PAX6), transcript variant 6, mRNA
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 443 ..... 467
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1358 ..... 1325

>NM_001258463_1 Homo sapiens paired box 6 (PAX6), transcript variant 5, mRNA
product length = 958
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 393 ..... 417
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1342 ..... 1317

>NM_001258462_1 Homo sapiens paired box 6 (PAX6), transcript variant 4, mRNA
product length = 958
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 455 ..... 479
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1404 ..... 1379

>NM_001804_5 Homo sapiens paired box 6 (PAX6), transcript variant 2, mRNA
product length = 958
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 443 ..... 467
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1392 ..... 1367

>NM_000200_4 Homo sapiens paired box 6 (PAX6), transcript variant 1, mRNA
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 541 ..... 565
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1448 ..... 1423

>NM_00127612_1 Homo sapiens paired box 6 (PAX6), transcript variant 3, mRNA
product length = 908
Forward primer 1 CCAGCCAGAGCCAGCATGCAGAACCA 25
Template 455 ..... 479
Reverse primer 1 GGTTGGTAGACACTGGTGCTGAAACT 26
Template 1362 ..... 1337
```



Computational Protein Analysis

In this section, the plan is to look exclusively at the **protein** of **PAX6**. The object is to use various software items to confirm what has already discovered from the various web resources. Often the software you will use will be exactly that which was used to determine the pre-computed results you browsed previously.

Predicting Protein Secondary Structure.

A first step is to look at ways to predict the protein secondary structure of the **PAX6** protein. Evidence from various sources suggests that the **PAX6** protein has **9** helices arranged in triplets, plus a few beta strands.

To save time, I show here the relevant section from the **Uniprot Feature Table**. The helical triplets are involved in binding. **2** triplets are to be found in the paired box region, the other in the homeobox a little further along. Here we will try one of the most sophisticated methods available, to predict, essentially from the primary sequence, what we already know. If you really wish, I also offer a supplementary exercise based around one of the earlier prediction methods, still used, but although faster, significantly less accurate than more modern methods.

| | | |
|-------------|-----------|----|
| Beta strand | 6 - 8 | 3 |
| Beta strand | 14 - 16 | 3 |
| Helix | 23 - 34 | 12 |
| Helix | 39 - 46 | 8 |
| Helix | 50 - 63 | 14 |
| Beta strand | 77 - 79 | 3 |
| Helix | 81 - 93 | 13 |
| Helix | 99 - 108 | 10 |
| Turn | 114 - 116 | 3 |
| Helix | 120 - 133 | 14 |
| Helix | 219 - 229 | 11 |
| Helix | 237 - 246 | 10 |
| Helix | 251 - 275 | 25 |

Early Secondary Structure Prediction Methods - GOR



The service considered by many to offer the most effective method of predicting secondary structure is called **Jpred**. This is developed by the Barton group now located at Dundee University. Over **80%** accuracy is claimed for **Jpred** predictions. Due to the inherent imprecision in defining the end positions of secondary structure elements, **80%** is pretty much as good as is practically possible.

Go to the **Barton Group** web site at:

<http://www.compbio.dundee.ac.uk>

and follow the link to the **Jpred 4** server. Copy and paste the **PAX6** protein into the appropriate text box. Click on **Make Prediction**.

Jpred 4
Incorporating Jnet

A Protein Secondary Structure Prediction Server

Home REST API About News F.A.Q. Help & Tutorials Monitoring Contact Publications

Input sequence (?)
Advanced options (click to show/hide)

Primary citation: Drozdetskiy A, Cole C, Procter J & Barton GJ. Nucl. Acids Res. (first published online April 16, 2015) doi: 10.1093/nar/gkv332 [link]. More citations: [link](#).

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With alacrity, **JPred** will report several hits with proteins of known **3D** structure (using **blast**). Links are offered to a number of entries in the **PDB** structure database. At least **2** of the **PDB** entries listed should be familiar.

Match found in PDB

The sequence you submitted is similar to those with known structure. These may provide a more accurate secondary structure assignment than a Jpred prediction.

If you still want to carry out a Jpred prediction click **continue**

Hits found

Show 25 entries

| PDB | Chain | Description | Blast E-value |
|------|-------|--------------------------|---------------|
| 6pax | A | HOMEBOX PROTEIN PAX-6 | 7e-70 |
| 1mdm | A | PAIRED BOX PROTEIN PAX-5 | 6e-53 |
| 1k78 | I | Paired Box Protein Pax5 | 6e-53 |
| 1k78 | E | Paired Box Protein Pax5 | 6e-53 |
| 1k78 | A | Paired Box Protein Pax5 | 6e-53 |
| 2k27 | A | Paired box protein Pax-8 | 3e-52 |
| 1pdn | C | PROTEIN (PRD PAIRED) | 1e-41 |
| 2cue | A | Paired box protein Pax6 | 1e-32 |

database. **Jpred** can then make its structure predictions based on an aligned "family" of proteins, rather than just one individual sequence. Intuitively at least, this has to be a fine idea. A multiple alignment of related proteins will typically represent far more evidence for prediction than any single protein.

Jpred offers the suggestion that it really does not make sense to continue. After all, if the **3D** structure is effectively known, why predict (guess?) the **2D** structure? The answer to this challenge being a petulant **"Because we want to!"**

Click purposefully on the **Continue** button. **JPred**, with a small sigh of exasperation, will submit your job and let you know how busy it is. **Jpred** typically takes a while as it has much to consider¹⁰².

Jpred will use **PSI-Blast** to align your sequence with all sequences deemed to be homologous, from a particularly appropriate

¹⁰² If the wait becomes unbearable, consider opening a new window/tab and moving on to the next section, returning to **Jpred** later.

JPred presents the results of running two secondary structure predictions, using the program **JNET**, based on two different representations of the alignment (**HMM** and **PSSM**, similar ideas that will be discussed at some point). Predicted helices are represented as red blocks, predicted beta sheets as green arrows. A consensus prediction is presented (**jnetpred**) as is an indication of prediction confidence (**JNETCONF**). Algorithms are also run to predict **coiled coils** (**Lupas**, with window sizes **21, 14, 28**). The first view of the results offered is a graphical overview aligned with your original single sequence.

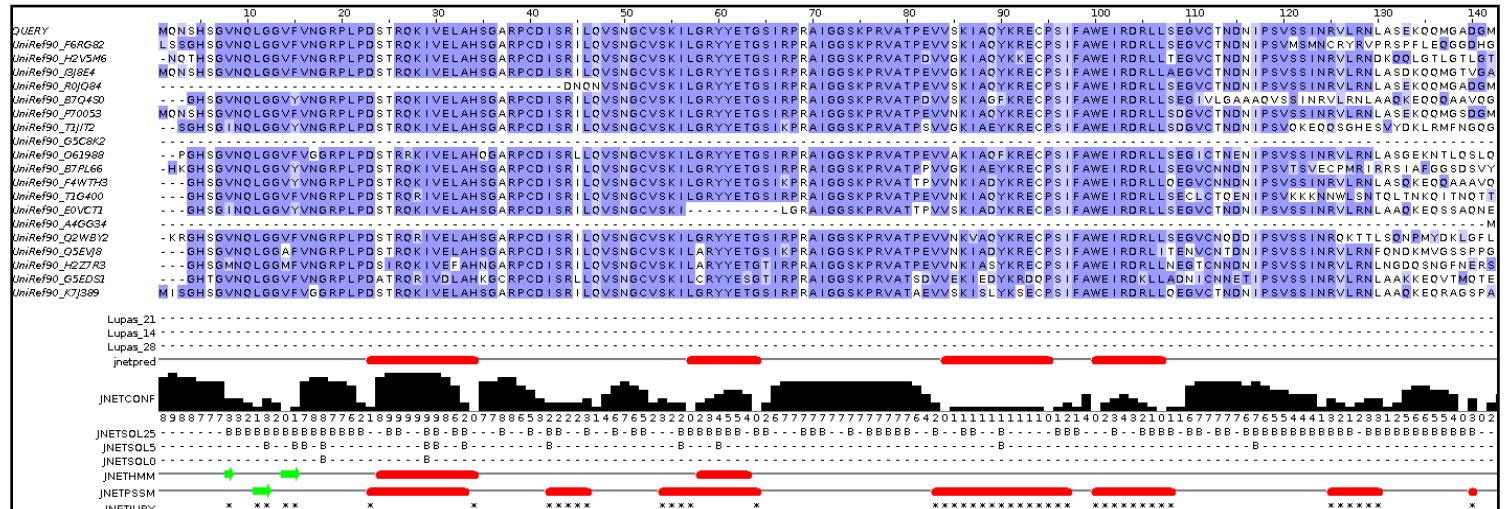
The full key to all the abbreviations used (and more information about JNet) can be displayed by clicking on the **details on acronyms used** link.

- LUPAS 21, LUPAS 14, LUPAS 28
Coiled-coil predictions for the sequence. These are binary predictions for each location.
 - JNETSOL25,JNETSOL5,JNETSOLO
Solvent accessibility predictions - binary predictions of 25%, 5% or 0% solvent accessibility.
 - JNetPRED
The consensus prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - JNetCONF
The confidence estimate for the prediction. High values mean high confidence. prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - JNetALIGN
Alignment based prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - JNetHMM
HMM profile based prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - jpred
jpred prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - JNETPSSM
PSSM based prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - JNETFREQ
Amino Acid frequency based prediction - helices are marked as red tubes, and sheets as dark green arrows.
 - JNETJURY
A '' in this annotation indicates that the JNETJURY was invoked to rationalise significantly different primary predictions.*

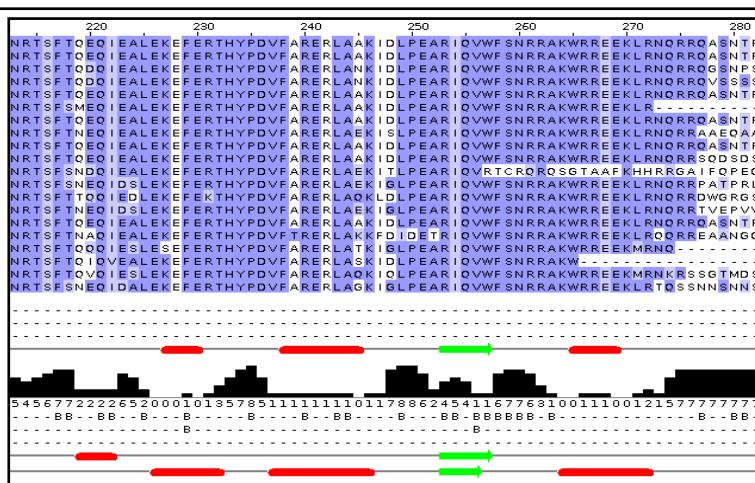
For a fuller view, elect to **View results in Jalview**¹⁰³. You will arrive at a page inviting you to select from various viewing options. The options are explained clearly, but to save you time reading and pain deciding, I suggest you go for **Option1** for the clearest view. This option does not confuse the picture by gapping your query sequence (and thus making it more difficult to associate structure predictions with regions of the **PAX6** protein) and does not force you to look at the entire, huge, **MSA** generated by **PSI-Blast**.

Jalview presents something very similar to the original view of the **Jpred** results. This time though, the most significant part of the **PSI-Blast MSA** from which the predictions were computed is displayed.

Here I have included the **Jalview** version of the predictions around the **PAX** region.



and those around the homeobox.

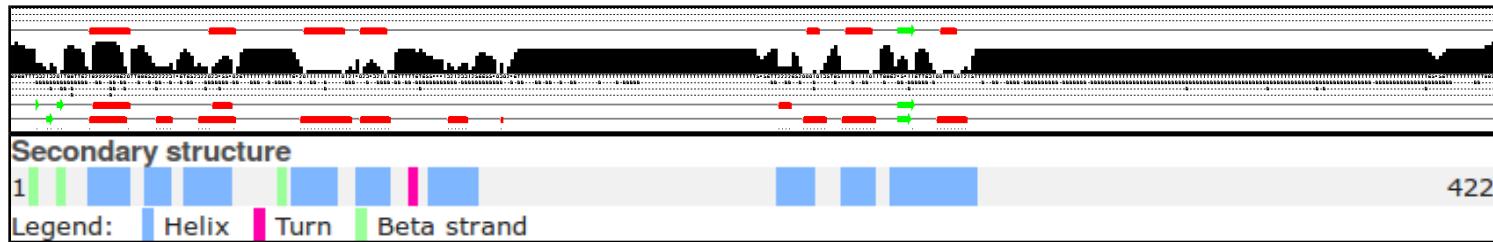


What protein database has Jpred chosen to search for protein sequences for the alignment upon which its predictions will be based?

Why do you suppose this database was used in preference to, say UniprotKB?

103 Should that not work, try **Full HTML**.

Also, I have lined up the entire prediction with the **Uniprot Feature Table** graphic as previously.



It would appear the helices predicted least confidently by **Jpred** are the same ones with which **GOR IV** (investigated in a supplementary exercise) had problems.

How would you rate the **Jpred** prediction overall?

Domain & Motif prediction.

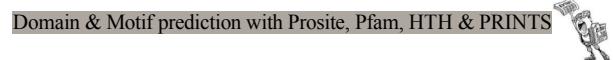
You will have discovered from, several information sources, that the **PAX6** human protein has two DNA binding domains. A paired box at the **N terminal** and a homeobox a little further along. Both of the domains include **Helix-Turn-Helix (HTH)** motifs. In this exercise, I invite you to investigate how you might have discovered these domains and motifs using the various freely available domain databases (discussed previously) and other feature prediction programs. Clearly, this is superfluous for this particularly, well documented protein, but a valuable option in other circumstances.

One approach would be to consider each relevant domain database in turn. Each major domain database has its own Home web site and customised software to take **Query** protein sequences, compare those sequences with domain representations (typically based on **Hidden Markov Models**) and to report convincing matches. This would work, but would be tedious as there are many viable databases to consider. It would be dangerous to rely on too few of the databases available as none is perfect. You need a consensus prediction to be sure you miss nothing.

Also, you would need to know which databases are particularly appropriate for each domain you considered might be present. All databases cannot be optimised for all types of domain (for example, the **SMART** database specialises only in domains that occur in signalling proteins).

So, let us not search individual domain databases in the main part of these exercises. Instead, I offer a supplementary exercise showing how you might search a representative selection individually for the domains you know to be present in **PAX6** human. I selected the **Prosite**, **Pfam** and **PRINTS** domain databases. If you get time to do this exercises, I particularly your attention to the **PRINTS** section. It illustrates how **PRINTS** just fails to see one of the domains that it should have found.

In this supplementary exercise also, I invite you to look at a simple **EMBOSS** program that tries (without complete success!) to discover **HTH** motifs.



Domain & Motif prediction with Prosite, Pfam, HTH & PRINTS

Here, let us just look at using **Interpro** to do the whole job. **Interpro** will search for all domains using all the appropriate domain databases. Essentially, it takes all the tedium and decision out of using the miscellany of domain searching resources.

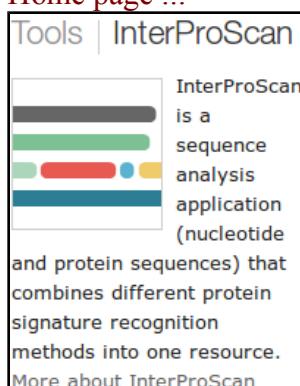


Interpro defines protein families according to the way that proteins match elements of a wide range of protein family databases, including all those we have discussed thus far. **Interpro** provides a search tool that will search all or any of the major protein family databases and assign **Interpro** family associations to the query protein(s) accordingly. To have a look at some of the possibilities offered by **Interpro**, Go to:

<http://www.ebi.ac.uk/interpro/>

If you were to enter the **PAX6** human protein into the obvious place on the **InterPro** home page, you would produce almost exactly the results you saw many pages back, when you were looking at **GeneCards**. Do this if you have the time and inclination.

By implication, **InterPro** offers a fuller experience via the **InterProScan** search tool. Other than the opportunity not to search **ALL** the domain databases, and having the results arranged slightly differently, I am unsure what the extra effort brings? Never mind, there are many things of which I am unsure, so, from the **InterPro** Home page ...



Select the **InterProScan** link. Here you will be offered the opportunity to download the **InterProScan** program.

I am not sure this is too useful an offer for most? But it is there.

For now, chose the online **Sequence search**.



Analysis of Proteins

You will arrive at a page that looks very similar to that from which you started, as far as the offer to run a domain search is concerned? Except! We now have **Advanced options**. Click on the **Advanced options**.

The **Advanced options** only allow you to choose which databases you wish to search and which feature prediction programs you wish to run. The default is to use all the databases and to run all the predictor programs. I struggle to imagine an occasion I would want to save the **EBI** servers a few cycles by considering which options to deselect, but it so nice to know I could if I wished to.

In passing, the offer to run the feature predictor programs in the **Other sequence features** section is relatively new. Of course, all these programs could be run individually from their home websites (follow the links behind the program names), in the same way as the domain databases can be searched individually. **Interpro** just aims to make thing easy for the user. The programs currently offered are:

Analyse your protein sequence

```
ARPCDISRILQVSNGCVSKILGRY
YETGSIRPRAIGGSKPRVATPEVVSKIAQYKRECPNSFA
WEIRDRLLSSEGVCNTNDNIPSV
SSINRVLRLASEKOQMGADGMYDKLRLMLNGOTGS
WGTRPGWYXPGTSVRGQPTQDGQQQQ
EGGGENTNSISSNEDSDEAOMRLQLKRLQRNRTSF
TOEQIEALEKEFERTHYPDVFAR
```

Advanced options

Select the applications to run: Uncheck all Select all

Member databases

- Families, domains, sites & repeats
 HAMAP PANTHER PfamA PIRSF ProDom PRINTS
 Prosite-Profiles SMART TIGRFAM Prosite-Patterns
- Structural domains
 Gene3d SUPERFAMILY
- Other sequence features
 Coils Phobius SignalP TMHMM

Search | Clear Example protein sequence

- **Coils** is a program for predicting **coiled coils**. **Jpred** employs a program called **Lupas** to do this. Possibly the same program, given the author of **Coils** is someone called **Lupas, A.**
- **Phobius** & **TMHMM** are programs to predict **Transmembrane regions** (essentially **hydrophobic, uncharged** regions). There is no reason to expect any **Transmembrane regions** in this protein.
- **SignalP** predicts the presence and location of **signal peptide cleavage sites** in amino acid sequences from different organisms. I am pretty certain that there is no reason to expect signal peptides in this protein.

Do you think it a good idea for **Interpro** to offer feature prediction programs as well as domain database searches?

Paste the human **PAX6** sequence into the patiently waiting box. Accept the default to “**do everything**”. Click on the **Search** button.

After several moments of deep thought, filtering and validating, you will be presented with a table of results looking very much like the one you saw when investigating **GeneCards**. There is, however, one important difference. In the **Unintegrated signatures** section, you will see that a **coiled coil** has been detected by the program **Coils**.

This was not included in the **GeneCards** information as **Interpro** has only recently included analysis using **Coils**. **GeneCards** will very probably catch up next time it is updated. It is also worth noting the **Jpred** does not predict a coiled coil anywhere in the protein?

The prediction matches the position of the first two helices of the homeobox. As you have seen, these lay along side each other.

Do you think the Coil prediction might be correct?

Notice that **Interpro** assigns both the **PAX** domain and the **Homeobox** domain of human **PAX6** to the **Interpro** family **Homeodomain-like**. Both of these associations are based on the hit behind the link **SSF46689**.



SCOP classification

- Root: [SCOP hierarchy in SUPERFAMILY \[SCOP_0\]](#) (11)
- Class: [All alpha proteins \[SCOP_46456\]](#) (284)
- Fold: [DNA/RNA-binding 3-helical bundle \[SCOP_46688\]](#) (14)
- Superfamily:** [Homeodomain-like \[SCOP_46689\]](#) (19)
 - Families: [Homeodomain \[SCOP_46690\]](#) (40)
 - Recombinase DNA-binding domain [SCOP_46728] (5)
 - Mb/SANT domain [SCOP_46739] (15)
 - SLIDE domain [SCOP_100998]
 - GARP response regulators [SCOP_81683]
 - DNA-binding domain of telomeric protein [SCOP_46745] (2)
 - Paired domain [SCOP_46748] (3)

Follow this link and you will see it leads to the **Homeodomain-like Superfamily** of the [HMM library and genome assignments server](#) database that specialises in very general (“at the **SCOP**¹⁰⁴ **superfamily** level) protein classifications. One **Superfamily** entry will typically correspond to a number of more specific domain definitions in other domain databases. Here you can see that the **Superfamily** domain **Homeodomain-like** includes both the **Homeodomain** & **Paired domain** Families.

The Gene3D database is similar to **superfamily** but based on the **CATH** database¹⁰⁵. It suggests the two **HTH** motifs of the paired box are both **Winged helix-turn-helix**. A different type of **HTH** to that of the **homeobox**. Possibly this is why the program **HTH** (see supplementary exercise) found the **homeobox HTH** easily, but really failed with the **paired box** features? CATH also appears to have an entry that includes the **homeobox**, but not the **paired box**?

Move back to your **InterProScan** results. Follow the link to the **Interpro family Homeodomain-like** ([IPR009057](#)). Click on the  button in the **Domain relationships** section to show the full list of **Homeodomain-like Interpro domains**.

Contributing signatures

Signatures from InterPro member databases are used to construct an entry.

| | | |
|--|---------------------|--------------------|
| | GENE3D | |
| | G3DSA:1.10.10.60 | (G3DSA:1.10.10.60) |
| | SUPERFAMILY | |
| | SSF46689 (SSF46689) | |

Note also the **Contributing signatures** in the top right hand corner of the page. Here is listed the domain databases that are searched to determine the presence of an **Interpro Homeodomain-like** domain.

Essentially, if **Gene3D** finds a match with its **Homeodomain-rel** domain and/or **Superfamily** finds a match with its **Homeodomain-like** domain, then **Interpro** acknowledges a match with its **Homeodomain-like** domain ([IPR009057](#)).

None of the other domain databases **Interpro** searches are used to determine membership of ([IPR009057](#)).

Domain relationships

- D **Homeodomain-like (IPR009057)**
 - D DNA binding HTH domain, Fis-type (IPR002197)
 - D DNA binding HTH domain, AraC-type (IPR018060)
 - D DNA binding HTH domain, Psq-type (IPR007889)
 - D DNA-binding HTH domain, TetR-type (IPR001647)
 - D HTH CenpB-type DNA-binding domain (IPR006600)
 - D Homeo-prospero domain (IPR023082)
 - D Homeobox domain (IPR001356)
 - D Homeodomain, ZF-HD class (IPR006455)
 - D Homeodomain, phBC6A51-type (IPR024978)
 - D Mor transcription activator (IPR014875)
 - D Rap1 Myb domain (IPR015010)
 - D Resolvase, HTH domain (IPR006120)
 - D SANT/Myb domain (IPR001005)
 - D SLIDE domain (IPR015195)
 - D SWIRM domain (IPR007526)
 - D Transposase IS30-like HTH domain (IPR025246)
 - D Transposase, Synechocystis PCC 6803 (IPR002622)
 - D TyrR family, helix-turn-helix domain (IPR030828)



To obtain an impression of how widely spread throughout nature is this domain. Click on the **Species** button on the left hand side of the page.

As you can see, this is a very popular domain. You can make this list enormous by injudicious employment of the expansion buttons. Why not? It amused me for a few moments anyway.

Proteins matched: Homeodomain-like (IPR009057)

Filtered by species: **Schizosaccharomyces pombe** (strain 972 / ATCC 24843) (Fission yeast)
(excludes child species) (change species)

Showing 1 to 20 of 27 results

| Accession | Protein name | Species | Domain architecture |
|-----------|--|---|---------------------|
| O13719 ★ | SWIRM domain-containing protein laf1 | Schizosaccharomyces pombe (strain 972 / ATCC 24843) (Fission yeast) | |
| O13788 ★ | SWI/SNF and RSC complexes subunit ssr1 | Schizosaccharomyces pombe (strain 972 / ATCC 24843) (Fission yeast) | |
| O13877 ★ | DNA-directed RNA polymerases I, II, and III subunit RPABC5 | Schizosaccharomyces pombe (strain 972 / ATCC 24843) (Fission yeast) | |
| O14013 ★ | RNA polymerase I-specific transcription initiation factor rrn5 | Schizosaccharomyces pombe (strain 972 / ATCC 24843) (Fission yeast) | |

By clicking on the appropriate button, you can get to either the protein sequences in **Fasta** format or list their accessions codes. Try a few, but be careful! It really does get you **ALL** the sequences, and that is often quite a lot, which will take time.

Key Species

| Key species | Number of proteins | FASTA | Protein IDs |
|---|--------------------|-------|-------------|
| Homo sapiens (Human) | 1065 | | |
| Danio rerio (Zebrafish) | 921 | | |
| Oryza sativa subsp. japonica (Rice) | 888 | | |
| Mus musculus (Mouse) | 868 | | |
| Arabidopsis thaliana (Mouse-ear cress) | 849 | | |
| Drosophila melanogaster (Fruit fly) | 478 | | |
| Caenorhabditis elegans | 195 | | |
| Escherichia coli (strain K12) | 95 | | |
| Saccharomyces cerevisiae (strain ATCC 204508 / S288c) (Baker's yeast) | 36 | | |
| Schizosaccharomyces pombe (strain 972 / ATCC 24843) (Fission yeast) | 27 | | |

Taxa

- cellular organisms 53295 proteins | FASTA | Protein IDs
 - Archaea 2417 proteins | FASTA | Protein IDs
 - Bacteria (eubacteria) 407749 proteins | FASTA | Protein IDs
 - Eukaryota (eucaryotes) 122129 proteins | FASTA | Protein IDs
- unclassified sequences 3327 proteins | FASTA | Protein IDs
- Viruses 711 proteins | FASTA | Protein IDs
- other sequences 14 proteins | FASTA | Protein IDs

¹⁰⁵ CATH is similar to SCOP in that it is another Structural classification database. We will look at it further, if and when I can ever make sense of it. It does also appear to have some parts that are not working properly? I investigate, I seek better persons than I to explain.

Multiple Sequence Alignment

Here we will look at some software tools to align some protein sequences. Before we can do that, we need some sequences to align. I propose we try all the human **homeobox** domains from the well annotated section of **UniprotKB**. Getting the sequences is a trifle clumsy, so concentrate now! There used to be a much easier way, but that was made redundant by foolish people intent on making the future ever more tricky!!

So, begin by going to the home of **Uniprot**:

<http://www.uniprot.org/>

Choose the **Advanced** option of the **Search** button.

First specify that you are only interested in **Human** proteins. To do this, set the first field to **Organism [OS]** and **Term to Human [9606]**.

Set the second field selector to **Reviewed** and the corresponding **Term** to **Yes** (that is, choose to find only **SwissProt** entries).

Click on the button to request a further field selection option. Set the new field to **Function**. Set the type of **Function** to **DNA binding**. Set the **Term** selection to **Homeobox**.

The screenshot shows the Uniprot search interface with the following search parameters:

- Term** section:
 - Organism [OS]: Human [9606]
 - Reviewed: Yes
- AND** section:
 - Function: DNA binding
 - Term: Homeobox
 - Length range: 50 - 70
 - Evidence: Any assertion method
- Add (+)** button: Located on the right side of the search interface.
- Search** button: Located at the bottom right of the search interface.

From previous investigations, you should be aware that a **Homeobox** domain is generally **60** amino acids in length. To avoid partial and/or really weird **Homeobox** proteins, set the **Length** range settings to recognise only **homeoboxes** between **50** and **70** amino acids long.

Leave the **Evidence** box as Any assertion method, one does not wish to be too fussy! Address the button with authority to get the search going.

The screenshot shows the search results table with the following columns:

| Entry | Entry name | Protein names | Gene names | Organism | Length |
|--------|-------------|--|----------------------------|----------------------|--------|
| Q9H2P0 | ADNP_HUMAN | Activity-dependent neuroprotector h... | ADNP, ADNP1, KIAA0784 | Homo sapiens (Human) | 1,102 |
| Q96G23 | CERS2_HUMAN | Ceramide synthase 2 | CERS2, LASS2, TMSG1 | Homo sapiens (Human) | 380 |
| O43186 | CRX_HUMAN | Cone-rod homeobox protein | CRX, CORD2 | Homo sapiens (Human) | 299 |
| P39880 | CUX1_HUMAN | Homeobox protein cut-like 1 | CUX1, CUTL1 | Homo sapiens (Human) | 1,505 |
| P35548 | MSX2_HUMAN | Homeobox protein MSX-2 | MSX2, HOX8 | Homo sapiens (Human) | 267 |
| Q9H9S0 | NANOG_HUMAN | Homeobox protein NANOG | NANOG | Homo sapiens (Human) | 305 |
| P43699 | NKX21_HUMAN | Homeobox protein Nkx-2.1 | NKX2-1, NKX2A, TITF1, TTF1 | Homo sapiens (Human) | 371 |
| P52952 | NKX25_HUMAN | Homeobox protein Nkx-2.5 | NKX2-5, CSX, NKX2.5, NKX2E | Homo sapiens (Human) | 324 |
| P23760 | PAX3_HUMAN | Paired box protein Pax-3 | PAX3, HUP2 | Homo sapiens (Human) | 479 |
| P26367 | PAX6_HUMAN | Paired box protein Pax-6 | PAX6, AN2 | Homo sapiens (Human) | 422 |

A fine miscellany of sequences will assemble upon your screen. Most seem to declare themselves in possession of a **Homeobox** or two (including **PAX6_HUMAN**), so I suggest a declaration of success.

Now save the entire list into a file using the [Download](#) button. Set the download to **uncompressed**. Make sure you have **all** sequences selected and that **Text** (i.e. EMBL or SwissProt) format selected. Press the **Go** button and do whatever it takes to ensure your results end up in a file residing on your **Desktop** called:

[human_homeobox_proteins.embl](#)

| | |
|---|---|
| <input type="radio"/> Download selected (0) | <input checked="" type="radio"/> Download all (239) |
| Format: Text | |
| <input type="radio"/> Compressed | <input checked="" type="radio"/> Uncompressed |
| Preview first 10 | |
| Go | |

```
ID ADNP_HUMAN          Reviewed;           1102 AA.
AC Q9H2P0; E1P5Y2; O94881; Q5BKU2; Q9UG34;
DT 01-NOV-2002, integrated into UniProtKB/Swiss-Prot.
DT 01-MAR-2001, sequence version 1.
DT 22-JUL-2015, entry version 131.
DE RecName: Full=Activity-dependent neuroprotector homeobox protein;
DE AltName: Full=Activity-dependent neuroprotective protein;
GN Name=ADNP; Synonyms=ADNP1, KIAA0784;
OS Homo sapiens (Human).
OC Eukaryota; Metazoa; Chordata; Craniata; Vertebrata; Euteleostomi;
OC Mammalia; Eutheria; Euarchontoglires; Primates; Haplorrhini;
OC Catarrhini; Hominidae; Homo.
OX NCBI_TaxID=9606;
RN [1]
RP NUCLEOTIDE SEQUENCE [mRNA].
RC TISSUE=Fetal brain;
RX PubMed=11013255; DOI=10.1074/jbc.M007416200;
RA Zamostiano R., Pinhasov A., Gelber E., Steingart R.A., Seroussi E.,
RA Giladi E., Bassan M., Wollman Y., Eyre H.J., Mulley J.C.,
```

Take a swift look at the file you have just created. Your neat list of **Human Homeobox** sequences will have transformed into a flood of **many SwissProt** format **UniProtKB** entries. Ugly, but what is required.

Search (**Control F**) for the term **DNA_BIND**.

It should occur many times (at least once per sequence) in the Feature Tables and most often refer to a **Homeobox** region.

In the **DNA_BIND** Feature Table entries, the position of the **Homeoboxes** are recorded and will be used by the next program to isolate the sequence of the **Homeoboxes**.

| | | | | |
|----|----------|------------|-------------|--|
| FT | CHAIN | 1 | 430 | Pre-B-cell leukemia transcription factor 2. |
| FT | | | | /FTId=PRO_0000049237. |
| FT | DNA_BIND | 244 | 306 | Homeobox; TALE-type. |
| FT | COMPBIAS | 137 | 145 | {ECO:0000255 PROSITE-ProRule:PRU00108}. |
| FT | MOD_RES | 136 | 136 | Poly-Ala. |
| FT | MOD_RES | 151 | 151 | Phosphoserine. |
| FT | | | | {ECO:0000269 PubMed:24275569}. |
| FT | | | | Phosphoserine. |
| FT | | | | {ECO:0000269 PubMed:18220336, |
| FT | | | | ECO:0000269 PubMed:18669648, |
| FT | | | | ECO:0000269 PubMed:20068231}. |
| FT | MOD_RES | 330 | 330 | Phosphoserine. |
| FT | | | | {ECO:0000269 PubMed:18669648, |
| FT | | | | ECO:0000269 PubMed:21406692}. |
| FT | CONFLICT | 393 | 393 | M -> I (in Ref. 1; CAA42503). |
| FT | | | | {ECO:0000305}. |
| SQ | SEQUENCE | 430 AA; | 45881 MW; | EF2FFA158C4DAF68 CRC64; |
| | | MDERLLGPPP | PGGGRRGLGL | VSGEPPGPGE PPAGGDPGGG SGGVPGRGK QDIDGILQQI |
| | | MTTIDQSLDE | AQAKKHALNC | HRMKPALFSV LCEIKEKIGL SIRSSQEEEP VPQLMRLDN |
| | | MLLAEGVAGP | EKGGGSAAAA | AAAAASGGGV SPDNSIEHSD YRSKLAQIRH IYHSELEKEYE |
| | | QACNEFTTHV | MNLLREQSRT | RPVAPKEMER MVSIIHRKFS AIQMQLKQST CEAVMILESR |
| | | FLDARRKRN | FSKQATEVLN | EYFYSHLSNP YPSEEAKEEL AKKCGITVVSQ VSNWFGNKRI |
| | | RYKKNTGKFQ | EEANITYAVKT | AVSVTQGGHS RTSSPTPPSS AGSGGSFNLS GSGDMFLGMP |
| | | GLNGDSYSAS | QVESLRHSMG | PGGYGDNLLG GQMYSPREMR ANGSWQEAVT PSSVTSPTEG |
| | | PGSVHSDTSN | // | |

Now to extract from the whole protein sequences you have saved in a file, the sequences of just the **Homeobox** domains. One way of doing this (possibly not the best), is to use an **EMBOSS** package program called **extractfeat**. This can be found in many places, including the Bioinformatics server at **Wageningen** in the Netherlands. Go to:

<http://emboss.bioinformatics.nl/>

EDIT
[aligncopy](#)
[aligncopypair](#)
[biased](#)
[codcopy](#)
[cutseq](#)
[degapseq](#)
[descseq](#)
[entret](#)
[extractalign](#)
[extractfeat](#)

Find the program **extractfeat** (in the **EDIT** section), and set it going.

Use the **Choose File** button to **upload** the **SwissProt** format sequences from **UniProtKB** that you saved in the file **human_homeobox_proteins.emb**.

Set Type of feature to extract field to DNA_BIND (Make sure you remove the “*”).

Set Value of feature tags to extract to Homeobox* (Make sure you append the “*” to ensure hits with, for example “homeoboxes”).

Set the Output sequence format to SwissProt (Fasta would do, but SwissProt retains more annotation).

Click on the **Run extractfeat** button to start **extractfeat** going. Many sequences of **60** amino acids (or so) in length will leap into view.

Input section

Select an input sequence. Use one of the following three fields:

1. To access a sequence from a database, enter the USA here:
2. To upload a sequence from your local computer, select it here: **Choose File** **human_home...oteins.emb**
3. To enter the sequence data manually, type here:

Additional section

Amount of sequence before feature to extract

Amount of sequence after feature to extract

Source of feature to display

Type of feature to extract **DNA_BIND**

Sense of feature to extract
(default is 0 - any sense, 1 - forward sense, -1 - reverse sense)

Minimum score of feature to extract **0.0**

Maximum score of feature to extract **0.0**

Tag of feature to extract

Value of feature tags to extract **Homeobox***

Output section

Output introns etc. as one sequence? **No**

Append type of feature to output sequence name? **No**

Feature tag names to add to the description

Output sequence format **SwissProt**

Run section

Email address:
If you are submitting a long job and would like to be informed by email when it finishes, enter your email address here

Run extractfeat **Reset**

OUTPUT FILE [outseq](#)

```
ID ADNP_HUMAN_754_814 Unreviewed;          61 AA.
DE [dna_bind] RecName: Full=Activity-dependent neuroprotector homeobox protein; AltName: Full=Activity-dependent neuroprotective protein;
SQ SEQUENCE 61 AA; 7330 MW; 2A08F4F3C18785D8 CRC64;
LDPKGHEDDS YEARKSFLTK YFNKQPYPTR REIEKLAASL WLWKSIAASH FSNKRKKCVR
D
//
ID CERS2_HUMAN_67_128 Unreviewed;          62 AA.
DE [dna_bind] RecName: Full=Ceramide synthase 2; Short=CerS2; AltName: Full=LAG1 longevity assurance homolog 2; AltName: Full=SP260; AltName: Full=Tumor metastasis-suppressor gene 1 protein;
SQ SEQUENCE 62 AA; 7373 MW; B94732A59CA60B9F CRC64;
LLNIKEKTRL RAPPNATLEH FYLTSGKQPK QVEVELLSRQ SGLSGRQVER WFRRRRNQR
PS
//
ID CRX_HUMAN_39_98 Unreviewed;          60 AA.
DE [dna_bind] RecName: Full=Cone-rod homeobox protein;
SQ SEQUENCE 60 AA; 7369 MW; B8E43274B30EBAC6 CRC64;
QRERRTTFTR SQLEELEALF AKTQYPDVYA REEVALKINL PESRVQVWFK NRRAKCRQR
//
```

Right click the [outseq](#) button and select **Save Link as...**. Do whatever it takes to save all your **Homeobox** domains into a file residing on your **Desktop** called:

homeobox_human.emb

Finally, we have some sequences with which to investigate the multiple sequence alignment programs.

Take a look at the file you have created. You should have many human **homeobox** domains in **SwissProt** format, looking rather as they did in your browser window. Happily **ClustalX**, the first multiple alignment program to be investigated, accepts multiple sequence **SwissProt** format files as input.

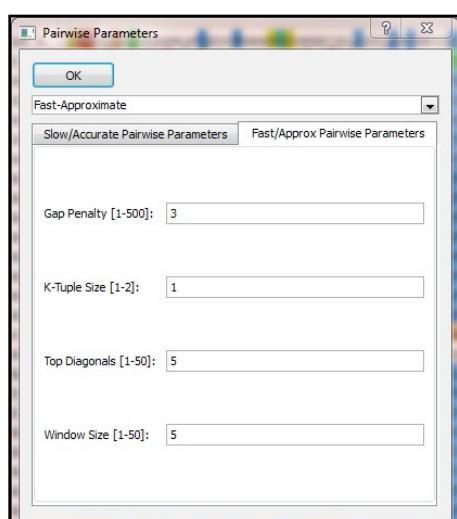
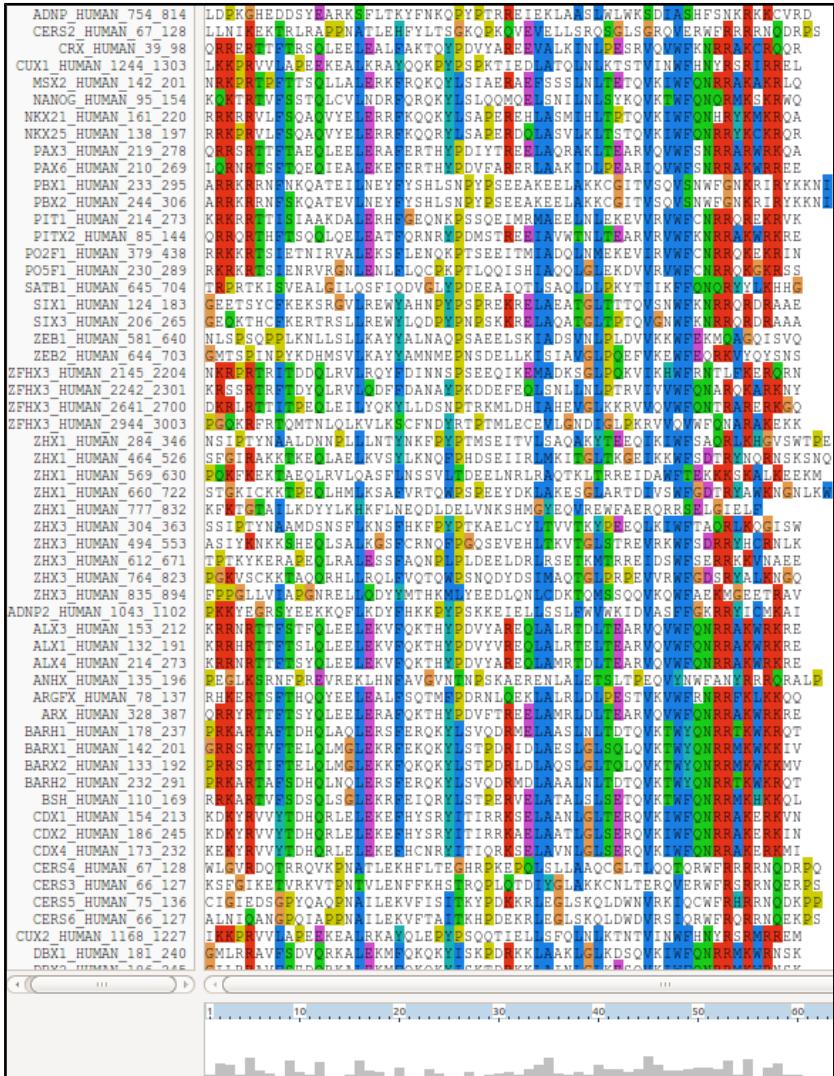
ClustalX is a part of the mostly widely known family of **multiple sequence alignments (msa)** programs, originating in the **1980s**. Until relatively recently, it was the only real option. **ClustalX** still has merit, although it lacks some of the sophistication of more recent programs. **ClustalX** runs on effectively all workstations and has a nice **Graphical User Interface (GUI)**. A good place for us to start. It is installed on your workstations.

Start up the program **ClustalX**¹⁰⁶. The **ClustalX** Graphical User Interface (GUI) will regally mount your screen.

Select **Load Sequences** from the **File** pull down menu and load your file of **homeobox** domains.

The sequences will arrange themselves colourfully. Many of the **homeoboxes** are similar enough to look convincing even before alignment. Note the “Manhattan skyline” under the sequences indicating the degree of conservation.

Font:  You might like to increase the **Font** size from the minute default setting designed for Hawks and Eagles, to something more comfortable. **24** works tolerably well for me.



From the **Alignment** pull down menu, go to the **Alignment parameters** menu and select **Pairwise Alignment Parameters**. Just for a moment, change the setting from **Slow-Accurate** to **Fast-Approximate**. Bring the corresponding parameters into view by clicking on **Fast/Approx Pairwise Parameters** tab¹⁰⁷.

Hopefully, we will have discussed the way **ClustalX** (and similar multiple alignment tools) work. Intuitively, it should not make a lot of difference how the initial pairwise comparison stage is conducted. However, it very often does.

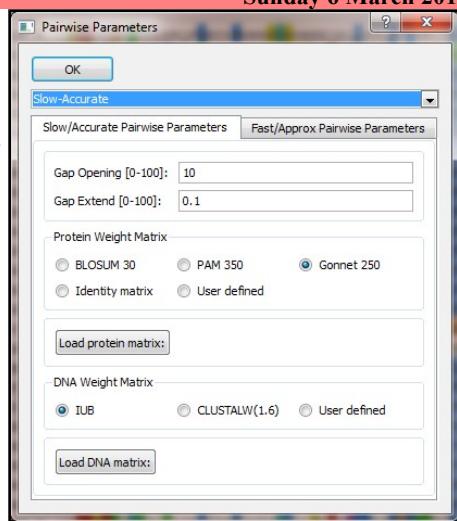
Specifically for this set of proteins, as well as generally, **ClustalX** will give a noticeably better alignment if the initial pairwise alignment stage is done carefully. Accordingly, reverse your whimsical setting change by moving back from **Fast-Approximate** to **Slow-Accurate**.

¹⁰⁶ Of course, you could run **Clustal** from websites all over the world if you wished. Specifically, it is available both at the **EBI** and the Bioinformatics server at **Wageningen**. Try it if you have time. You get the same results but will, sadly, lose the pretty interface.

<http://www.ebi.ac.uk/Tools/clustalw2/index.html>
<http://www.bioinformatics.nl/tools/clustalw.html>

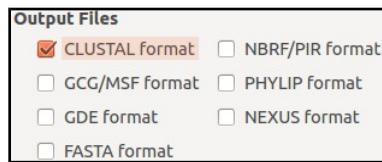
¹⁰⁷ The **Fast-Approximate** algorithm is essential that which the database searching program **fasta** employs. Assuming we have discussed how **fasta** works, it should require no further explanation here.

Click on the **Slow/Accurate Pairwise Parameters** tab for a final look at the default parameters to be used. The **Slow-Accurate** option is essentially a version of **Global Alignment** algorithm we will have discussed previously. Hopefully, all the parameter options will therefore be familiar to you.

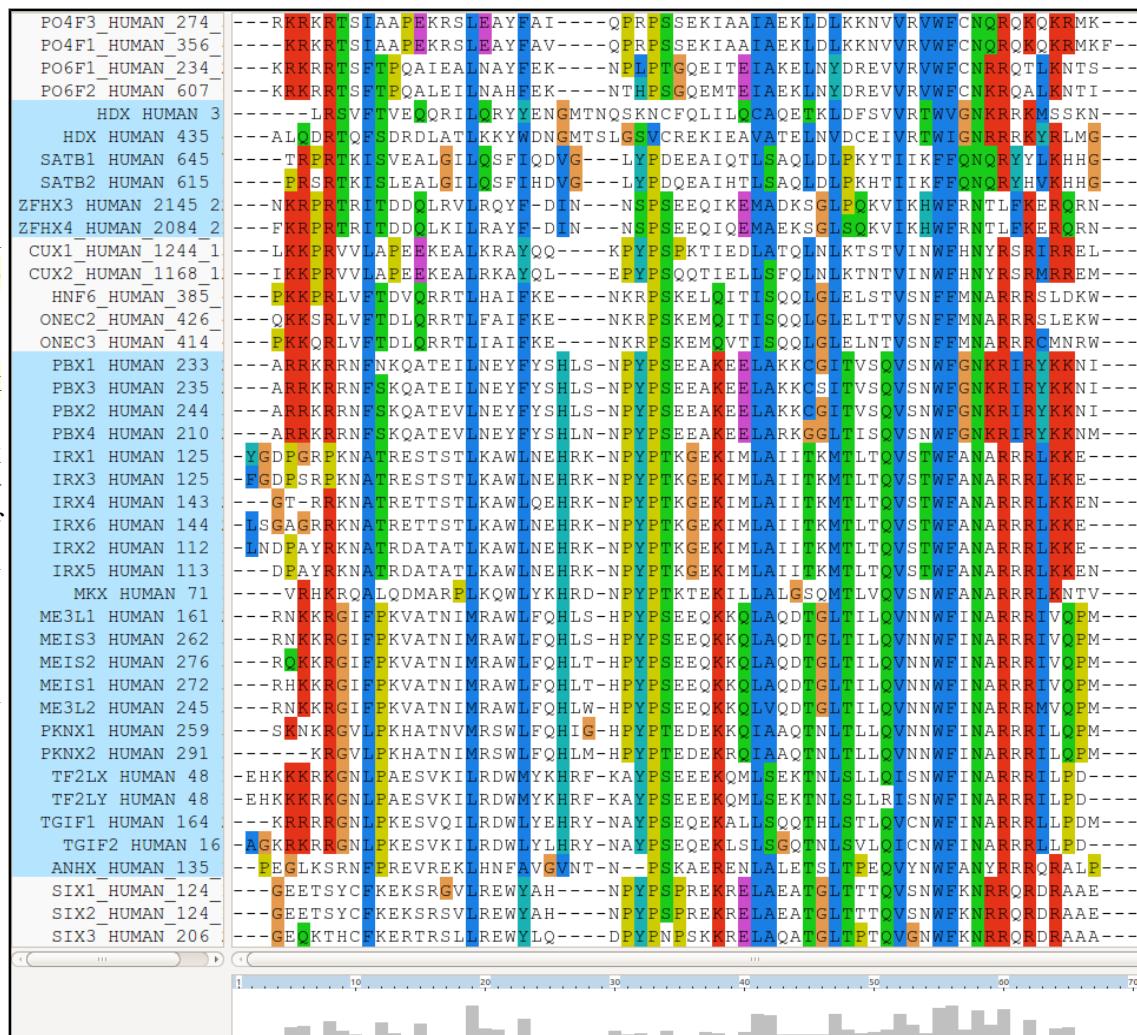


I will assume both sets of parameters at least seem familiar? If not please ask. The default **Slow/Accurate Pairwise Parameters** you now have in view are fine. Click the **OK** button to dismiss the **Pairwise Parameters** window.

Before proceeding, save the **homeobox** sequences in **FASTA** format, which will better suit the other **msa** programs we will try. Do this by selecting **Save sequences as...** from the **File** pull down menu. Deselect **CLUSTAL format**, select **FASTA format**. Click **OK**. A file called **homeobox_human.fasta** will be created. Take a look to check it is as you would expect.



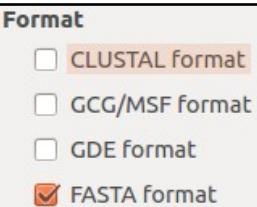
Strangely, saving your sequences in **FASTA** format convinces **clustalx** that it should now output its alignments in **FASTA** format. To prevent this, again select **Output Format Options** from the **Alignments** pull down menu. Deselect **FASTA format** and select **CLUSTAL format**. Click **OK**.



From the **Alignment** pull down menu, select **Do Complete Alignment**.

Accept the default names for output files and click on the **OK** button. **ClustalX** will start to think deeply and eventually come up with it view of how the **homeobox** domains should be aligned.

Not a bad first try. From an entirely non scientific, cosmetic viewpoint, the ragged ends offend a trifle, as does the gap just before position 30!



Analysis of Proteins

In reality, these features might be very interesting, but here I go for pretty!

So, just to investigate what is possible, select all the **homeobox** sequences that are causing the gap around position **30** by clicking on their names (quite a lot of them I fear). Hold the **Ctrl** key down to allow multiple selection.

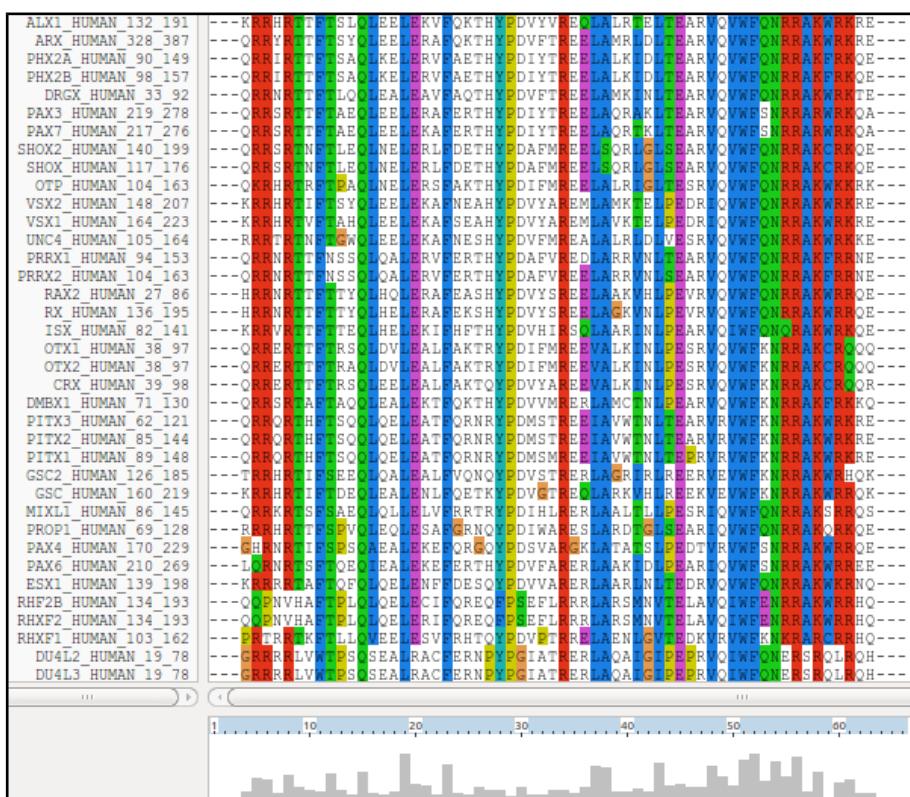
Once you have them all, go to the **Edit** pull down menu and select **Cut Sequences**. Then select **Remove Gap-Only columns** from the **Edit** pull down menu. Nasty gap gone ... along with all scientific credibility, but ... never mind.

You could recompute the alignment from scratch with the reduced sequence set, but you should end up with the same answer, of course. Just for the sake of it, select **Select All Sequences** from the **Edit** pull down menu. Then select **Remove All gaps** from the **Edit** pull down menu and confirm your intentions. You are now back where you started, but without the sequences that mess up the alignment intolerably!

Save your filtered set of sequences in a file. From the **File** pull down menu select **Save Sequences as...**. Choose **FASTA** format only.

The default file name is OK, even though it will overwrite the original sequences. I am convinced the sequences eliminated would not be aligned convincingly with any of the tools we have at hand. Let us lose them! Press the **OK** button.

From the **Alignment** pull down menu, select **Output Format Options** and select **CLUSTAL format** only. Again, from the **Alignment** pull down menu, select **Do Complete Alignment**. Accept the default names for the output files. This will overwrite your previous efforts, but no matter. More deep thought. Well, I got back to where I was, no gaps around position **30** but still with ragged ends!



You will recall from earlier that the **Prosite** pattern for a **homeobox** is the ever memorable:

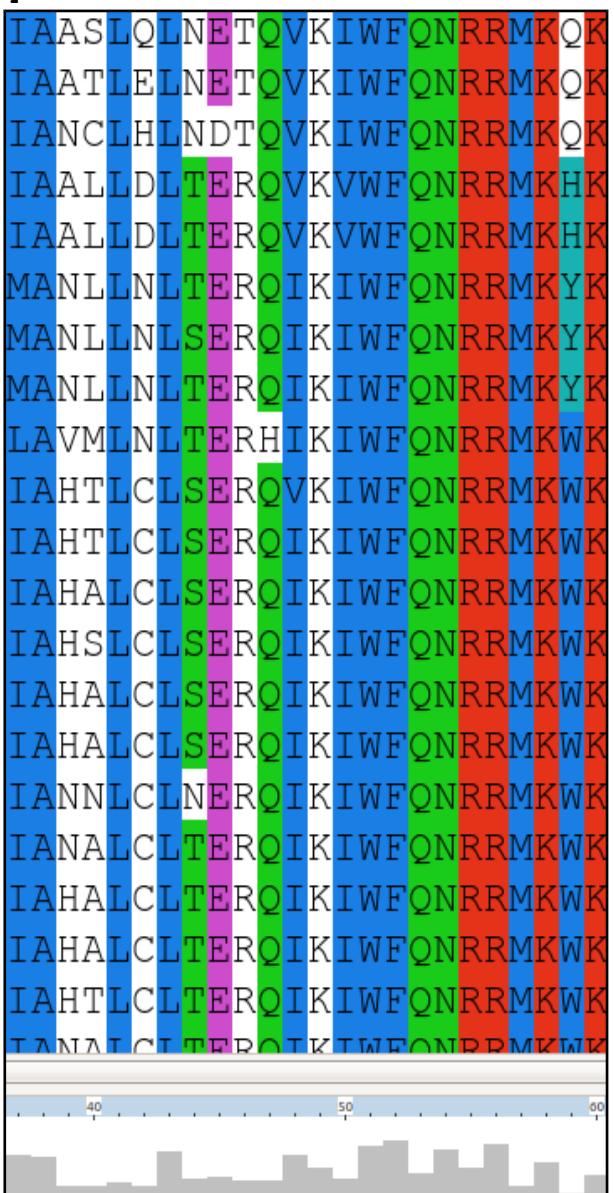
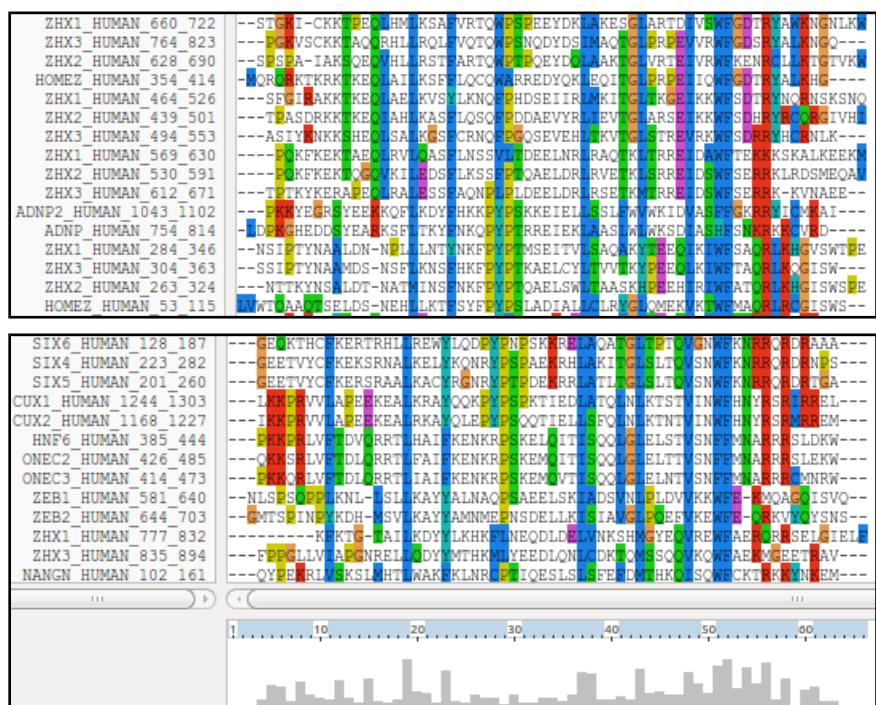
[LIVMFYG] - [ASLVR] - x (2) - [LIVMSTACN] - x - [LIVM] - {Y} - x (2) - {L} - [LIV] - [RKNQESTAIY] - [LIVFSTNKH] - W - [FYVC] - x - [NDQTAH] - x (5) - [RKNAIMW]

This corresponds to positions **37** to **60** in this alignment. See that the “Manhattan Skyline” is encouraging in the parts of this region that matter.

Note that the profile **Tryptophan**, in position **51**, is **very** consistent, but not quite **100%** as suggested by the **Prosite** pattern¹⁰⁸. The **W** was even conserved in the sequences that were cosmetically removed.

Position **53** is not conserved (“-x-”) according to the **Prosite** pattern. In the alignment segment offered here, it looks like a pretty consistent **Q**. However, the “**Manhattan skyline**” at this position is very low, suggesting that the sequences in view might not be typical of the whole alignment set. Which, upon checking they are not!

Looking through this alignment, I get the feeling I could design a better, stricter pattern for the region between **37** and **60**. Possibly true, but remember the pattern in **Prosite** aims to represent the conservation of **Homeobox** domains in **ALL** organisms. Here we have only sequences from **Human**.



Of course, things are not quite so convincing throughout. If you look at the top and bottom few sequences, you will see that **ClustalX** had its moments of uncertainty.

Note, however, the consistent **W** in position **50** despite the surrounding crumble.

¹⁰⁸ From the “**Manhattan Skyline**”, you can see the conservation is less than **100%**. Less conserved than the **F** that immediately follows in fact? Look at your alignment, the “**Manhattan Skyline**” does not seem to reflect reality? The **W** is **very** well conserved, although the scoring matrices would regard any deviation from **W** as serious? I need to find out more about how the **Skyline** is computed.

Now to show existence of some **msa** program options available on the web. There are many. They are available from a number of server sites. An obvious place to start has to be the **EBI** page dedicated to **MSA**. Go to:

<http://www.ebi.ac.uk/Tools/msa/>

Offered here is an impressively full selection of popular, current generation **msa** tools. Each is accompanied by advice to guide the choice of tool to best fit the circumstances. Each tool is provided with a link to its **Launch** interface. All the **Launch** interfaces are very consistent. Once you have run one of the **msa** options, you should have no trouble running any of the others.

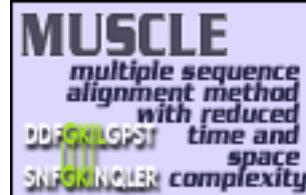
| | |
|---|---|
| Clustal Omega  | MUSCLE  |
| New MSA tool that uses seeded guide trees and HMM profile-profile techniques to generate alignments.
Suitable for medium-large alignments. | Accurate MSA tool, especially good with proteins.
Suitable for medium alignments. |
|  Launch Clustal Omega |  Launch MUSCLE |
| ClustalW2  | MView  |
| Popular MSA tool that uses tree-based progressive alignments. Suitable for medium alignments. | Transform a Sequence Similarity Search result into a Multiple Sequence Alignment or reformat a Multiple Sequence Alignment using the MView program. |
|  Launch ClustalW2 |  Launch MView |
| DbClustal  | T-Coffee  |
| Create a Multiple Sequence Alignment from a protein BLAST result using the DbClustal program. | Consistency-based MSA tool that attempts to mitigate the pitfalls of progressive alignment methods. Suitable for small alignments. |
|  Launch DbClustal |  Launch T-Coffee |
| Kalign  | WebPRANK |
| Very fast MSA tool that concentrates on local regions.
Suitable for large alignments. | The EBI has a new phylogeny-aware multiple sequence alignment program which makes use of evolutionary information to help place insertions and deletions.
Try it out at WebPRANK . |
|  Launch Kalign | |
| MAFFT  | |
| MSA tool that uses Fast Fourier Transforms. Suitable for medium-large alignments. | |
|  Launch MAFFT | |

Here I intend to align again the human **homeoboxes** with just one of the tools on offer. Then take a quick look at how the machine generated multiple alignment can be manually edited using **jalview**, a program that is installed on your workstation and that you have already used as an alignment viewer when investigating **Pfam**.

Then I will invite you to try a few of the other options for yourself and see that they do not all produce the same alignment! Differences reflect not only the parameters selected, which we will have discussed, but also the particular objectives of the program selected. For example, a multiple protein sequence alignment optimal for investigating conservation of protein structure might well not be identical to one best representing protein evolution.

Used to align the **Homeobox** sequences used in this exercise, I do not expect you will see much difference between the outputs of any of these options. They will all work sufficiently on such a simple data set.

The program whose use I choose to describe carefully, leading on to a short **jalview** exercise is **MUSCLE**. I choose thus as **MUSCLE** is now the first choice of most of the people with whom I work. Almost as popular are **Clustal Omega**, **MAFFT** and, for **phylogeny**, **PRANK**.



So the plan now is to use **MUSCLE**¹⁰⁹ to align again the **homeobox** sequences previously aligned with **clustalX**. **MUSCLE** works in a way similar to **clustalX** but it takes rather more care in the generation of the **Guide Tree** used to control the order of pairwise construction of the final multiple alignment¹¹⁰. Particularly for more difficult alignments, **MUSCLE** should do a better job than **clustalX**. The alignment you will generate here will certainly be different. I leave you to judge for yourselves whether it is better.

Start by requesting to [Launch MUSCLE](#).

Use the **Choose File** button to upload the file containing the FASTA format **homeobox** sequences, **homeobox_human.fasta**. This file should no longer included the sequences with a mess around position **30**.

STEP 1 - Enter your input sequences

Enter or paste a set of sequences in any supported format:

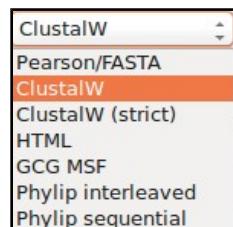
Take a look at the **Set your Parameters** section of the page.

STEP 2 - Set your Parameters

OUTPUT FORMAT: ClustalW ▾

The default settings will fulfill the needs of most users and, for that reason, are not visible.

More options... *(Click here, if you want to view or change the default settings.)*



There are a number of **OUTPUT FORMATS** offered. For a quick glance at your results, both **ClustalW** or **HTML** are fine. Here I suggest it would be nice to generate an output that can be downloaded and viewed in **Jalview**¹¹¹. The default **ClustalW** or **Pearson/FASTA** serve for this purpose. As **ClustalW** looks more like an alignment in the web page, I choose **ClustalW**¹¹².

The **EBI** site speaks the truth when it claims that “*The default settings will fulfill the needs of most users and, for that reason, are not visible.*”. But this is obscenely patronizing advice! so click the [More options...](#) button anyway.

I confess myself confused at the lack of any meaningful options to consider? I was expecting at least the **gap open** and **gap extension penalty** options (available elsewhere, including **Wageningen**), plus a way to change the **scoring matrix**. I have inquired why things are as they are. No practical issue here, as I intended to suggest the defaults whatever they were.

| | |
|-------------------------------------|---------------------|
| STEP 2 - Set your Parameters | |
| OUTPUT FORMAT: | ClustalW |
| OUTPUT TREE | OUTPUT ORDER |
| none | aligned |

Look at the range of settings for the **OUTPUT TREE** parameter. **none** is indeed the thinking persons choice, but ...

How do the options for the **OUTPUT TREE** relate to the output files of **ClustalX** and the difference between the way that **ClustalX** and **muscle** work?

Comment on how one might choose between the range of options offered for the aligned parameter?

¹⁰⁹ Available from a variety of websites in addition to the **EBI**, including the Bioinformatics server at **Wageningen**:
<http://www.bioinformatics.nl/tools/muscle.html>

110 As discussed, superficially at least, previously. I hope.

111 The java alignment editor and viewer you used to look at the **Pfam** alignments earlier.

112 But feel free to try the others. **HTML** is the default at Wageningen. The **Phylip** formats are the best if you are going to analyse your output further with the phylogeny programs of the **PHYLIP** package.

After considering these enigmas, or before if you prefer, Click on the **Submit** button and sit back to admire **muscle** in action.

The alignment that is computed is, superficially at least, similar to that offered by **ClustalX**.

The alignment that is computed is, superficially at least, similar to that offered by **ClustalX**.

| | |
|-----------------------|--|
| ISL2_HUMAN_191_250 | --TTRVRTVLNEKQLHTLRTCYAANPRPDALMKEQLVEMTGLSPRVIRWFONKRCKDKK |
| ISL1_HUMAN_181_240 | --TTRVRTVLNEKQLHTLRTCYAANPRPDALMKEQLVEMTGLSPRVIRWFONKRCKDKK |
| LHX2_HUMAN_266_325 | --TKRMRTSFKHQLRRTMKSYFAINHNPDAKDLKQLAQKTGLTKRVLQWFONARAKFRR |
| LHX9_HUMAN_267_326 | --TKRMRTSFKHQLRRTMKSYFAINHNPDAKDLKQLAQKTGLTKRVLQWFONARAKFRR |
| LHX6_HUMAN_219_278 | --AKRARTSFTAEOLQVMQAQFAQDNNPDAQTLOKLAQKTGLTKRVLQWFONCRARHKK |
| LHX8_HUMAN_225_284 | --AKRARTSFTADOLQVMQAQFAQDNNPDAQTLOKLAQKTGLTKRVLQWFONCRARHKK |
| ZFHX3_HUMAN_2641_2700 | --DKRLRTTITPEOLEILYQKYLLDSNPTRKMLDHIAHEVGLKRRVVQWFONTRARERK |
| ZFHX4_HUMAN_2560_2619 | --DKRLRTTITPEOLEILYQKYLLDSNPTRKMLDHIAHEVGLKRRVVQWFONTRARERK |
| ZFHX2_HUMAN_1857_1916 | --DKRLRTTILPEOLEILYQWYMDSNPTRKMLDCISEEVGLKRRVVQWFONTRARERK |
| ZFHX2_HUMAN_2065_2124 | --QRRYRTOMSSLQLKIMKACYEAYRTPTMQCEVLGEEIGLPKRVIVWFONARAKEKK |
| ZFHX3_HUMAN_2944_3003 | PGQKFRTRQMTNLQLKVLKSCFNDYRTPTMLECEVLGNDIGLPKRVIVWFONARAKEKK |
| ZFHX4_HUMAN_2884_2943 | --HKKRFRTOQMSNLQLKVLKACFSYRTPTMQECEMLGNEIGLPKRVIVWFONCRARHKK |
| LMX1A_HUMAN_195_254 | --PKRPTILTQQRRAFKASFEVSSKPCRKVRETLAAETGLSVRVVQWFONQRAKMKK |
| LMX1B_HUMAN_219_278 | --PKRPTILTQQRRAFKASFEVSSKPCRKVRETLAAETGLSVRVVQWFONQRAKMKK |
| LHX1_HUMAN_180_239 | --RRGPRTTIKAKQLETLKAFAAATPKPTRHIREQLAQETGLNMNRVIQWFONRRSKERR |
| LHX5_HUMAN_180_239 | --RRGPRTTIKAKQLETLKAFAAATPKPTRHIREQLAQETGLNMNRVIQWFONRRSKERR |
| LHX3_HUMAN_157_216 | --AKRPTTTITAKQLETLKSAYNTSPKPARHVREQLSSETGLDMRVRVQWFONRRAKEKR |
| LHX4_HUMAN_157_216 | --AKRPTTTITAKQLETLKSAYNTSPKPARHVREQLSSETGLDMRVRVQWFONRRAKEKR |
| | : : . . : : : : |
| ZHX1_HUMAN_777_832 | GIELF |
| ZHX3_HUMAN_835_894 | AV--- |
| ZEB2_HUMAN_644_703 | NS--- |
| ZEB1_HUMAN_581_640 | VQ--- |
| HOMEZ_HUMAN_53_115 | SWS-- |
| ZHX2_HUMAN_263_324 | SWSPE |
| ZHX3_HUMAN_304_363 | SW--- |
| ZHX1_HUMAN_284_346 | SWTPE |
| NANGN_HUMAN_102_161 | EM--- |
| ADNP_HUMAN_754_814 | D--- |
| ADNP2_HUMAN_1043_1102 | AI--- |
| ZHX1_HUMAN_569_630 | KEEKM |
| ZHX2_HUMAN_530_591 | MEQAV |
| ZHX3_HUMAN_612_671 | EE--- |

At the very bottom of the page, **muscle** whines:

PLEASE NOTE: Showing colors on large alignments is slow.

So click the **Show Colors** button at the top of the page and try to live with the pain of such gross Trans-Atlantic inept spelling in a European site!!! Good Grief! They get everywhere!!

Well, an improvement I suppose? Colours are very useful (even slow ones) in the interpretation of alignments. Various colour schemes are used to clarify the message of alignments. Colouring can indicate shared amino acid properties not immediately evident when the letter representations differ.

| | |
|-----------------------|--|
| ISL2_HUMAN_191_250 | --TTRVRTVLNEKQLHTLRTCYAANPRPDALMKEQLVEMTGLSPRVIRWFONKRCKDKK |
| ISL1_HUMAN_181_240 | --TTRVRTVLNEKQLHTLRTCYAANPRPDALMKEQLVEMTGLSPRVIRWFONKRCKDKK |
| LHX2_HUMAN_266_325 | --TKRMRTSFKHQLRRTMKSYFAINHNPDAKDLKQLAQKTGLTKRVLQWFONARAKFRR |
| LHX9_HUMAN_267_326 | --TKRMRTSFKHQLRRTMKSYFAINHNPDAKDLKQLAQKTGLTKRVLQWFONARAKFRR |
| LHX6_HUMAN_219_278 | --AKRARTSFTAEOLQVMQAQFAQDNNPDAQTLOKLAQKTGLTKRVLQWFONCRARHKK |
| LHX8_HUMAN_225_284 | --AKRARTSFTADOLQVMQAQFAQDNNPDAQTLOKLAQKTGLTKRVLQWFONCRARHKK |
| ZFHX3_HUMAN_2641_2700 | --DKRLRTTITPEOLEILYQKYLLDSNPTRKMLDHIAHEVGLKRRVVQWFONTRARERK |
| ZFHX4_HUMAN_2560_2619 | --DKRLRTTITPEOLEILYQKYLLDSNPTRKMLDHIAHEVGLKRRVVQWFONTRARERK |
| ZFHX2_HUMAN_1857_1916 | --DKRLRTTILPEOLEILYQWYMDSNPTRKMLDCISEEVGLKRRVVQWFONTRARERK |
| ZFHX2_HUMAN_2065_2124 | --QRRYRTOMSSLQLKIMKACYEAYRTPTMQCEVLGEEIGLPKRVIVWFONRRSKERR |
| ZFHX3_HUMAN_2944_3003 | PGQKFRTRQMTNLQLKVLKSCFNDYRTPTMLECEVLGNDIGLPKRVIVWFONARAKEKK |
| ZFHX4_HUMAN_2884_2943 | --HKKRFRTOQMSNLQLKVLKACFSYRTPTMQECEMLGNEIGLPKRVIVWFONCRARHKK |
| LMX1A_HUMAN_195_254 | --PKRPTILTQQRRAFKASFEVSSKPCRKVRETLAAETGLSVRVVQWFONQRAKMKK |
| LMX1B_HUMAN_219_278 | --PKRPTILTQQRRAFKASFEVSSKPCRKVRETLAAETGLSVRVVQWFONQRAKMKK |
| LHX1_HUMAN_180_239 | --RRGPRTTIKAKQLETLKAFAAATPKPTRHIREQLAQETGLNMNRVIQWFONRRSKERR |
| LHX5_HUMAN_180_239 | --RRGPRTTIKAKQLETLKAFAAATPKPTRHIREQLAQETGLNMNRVIQWFONRRSKERR |
| LHX3_HUMAN_157_216 | --AKRPTTTITAKQLETLKSAYNTSPKPARHVREQLSSETGLDMRVRVQWFONRRAKEKR |
| LHX4_HUMAN_157_216 | --AKRPTTTITAKQLETLKSAYNTSPKPARHVREQLSSETGLDMRVRVQWFONRRAKEKR |
| | : : . . : : : : |
| ZHX1_HUMAN_777_832 | GIELF |
| ZHX3_HUMAN_835_894 | AV--- |
| ZEB2_HUMAN_644_703 | NS--- |
| ZEB1_HUMAN_581_640 | VQ--- |
| HOMEZ_HUMAN_53_115 | SWS-- |
| ZHX2_HUMAN_263_324 | SWSPE |
| ZHX3_HUMAN_304_363 | SW--- |
| ZHX1_HUMAN_284_346 | SWTPE |
| NANGN_HUMAN_102_161 | EM--- |
| ADNP_HUMAN_754_814 | D--- |
| ADNP2_HUMAN_1043_1102 | AI--- |
| ZHX1_HUMAN_569_630 | KEEKM |
| ZHX2_HUMAN_530_591 | MEQAV |
| ZHX3_HUMAN_612_671 | EE--- |

But any decoration available here is far short of what can be achieved with **Jalview**, so click on the **Download Alignment File** button to save your alignment in a file on your **Desktop** called:

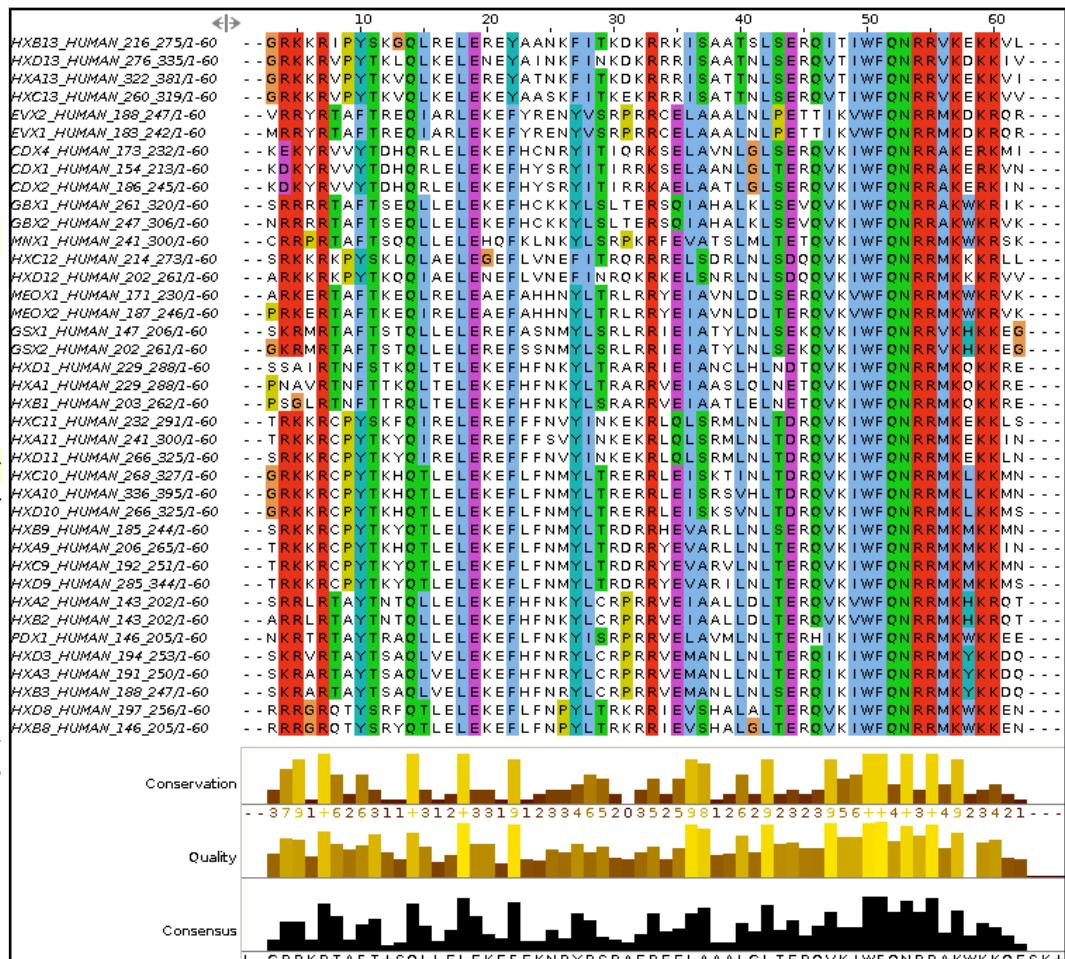
homeobox_human_muscle.aln

Start up **Jalview** from the **Windows Start** menu¹¹³. Close down all the example outputs it sees fit to show you on start up. From the **File** pull down menu choose **from File** from the **Input Alignment** option. Locate and load the file **homeobox_human_muscle.aln**.

The default view is a trifle bland. Try a few of the options from the **Colour** pull down menu.

You could try the same colour scheme used by **ClustalX**, for example.

Now the **MUSCLE** and massaged **ClustalX** alignments look even more similar! In the nicely aligned regions at least.

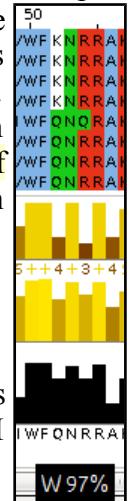


There are many **Jalview** features that merit investigation. Have a look around if you have time. In particular, **Jalview** will compute simple phylogenetic trees for you employing a number of methods (**Calculate Tree** from the **Calculate** pull down menu). Try it, but be aware this is only sensible if you were very sure of your alignment (and have a few less sequences maybe?).

Jalview is made by the same group as produce **JPred**. You could send your alignment for **Secondary Structure Prediction** via the **Web Service** pull down menu, if you wished.

A very important purpose of **Jalview** is to allow users to edit alignments as well as just to view them. For example, hold down the **Shift** key, click and hold on any amino acid at the edge of a gap, slide left and right and see that you can introduce and/or alter the position of gaps. It is very important to be able to edit alignments generated by even the best of programs. As I hope has been made clear, the alignment algorithms are crude. If you know something about the sequences you are aligning it is very reasonable to suppose you can improve upon the computer's alignments. **Jalview** tries to make this possibility easy. Look through some of the other **Edit** pull down menu options, it does not matter how much you mangle your alignment, you can always make another one.

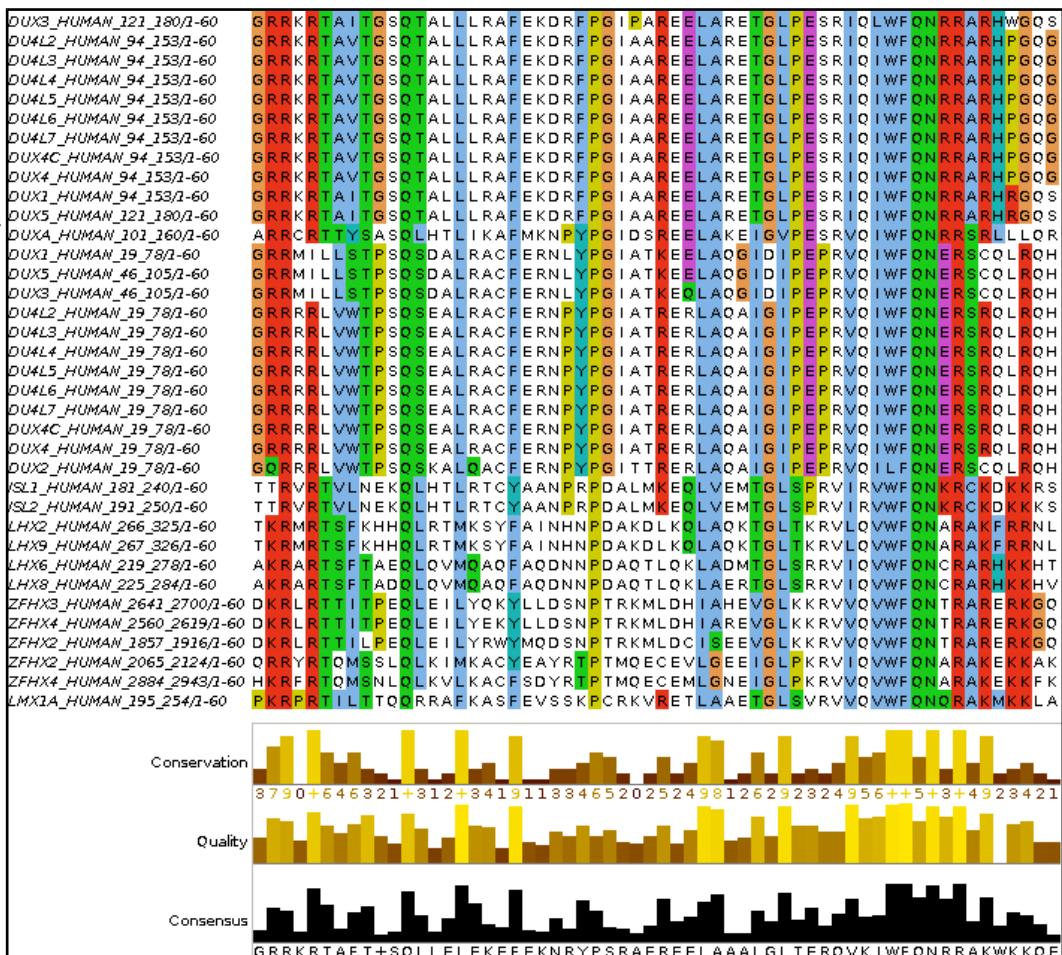
Finally, take a look at the **Jalview "Manhattan Skyline"** for the highly conserved **W** at position **50**. This seems a much more reasonable representation of the "truth" than **clustalX** managed? I am not sure what I believe at this point.



You can also **Select** and **Cut** sequences in a way similar to that you employed with **clustalx**. I could not resist it! I removed all the ugly sequences that caused the gaps at the start and finish of the alignment (just select their names and then select **Cut** or **Delete** from the **Edit** menu). I achieved the gap-free beautiful alignment illustrated.

Of course, **Jalview** does not compute alignments, so once I had removed all the unfortunate proteins, I had to use an **Edit** option to tidy up my meddling. I used **Remove Empty Columns** to get rid of the gap columns at the start of the alignment. The gaps at the end just melted away once the sequences that supported their presence were removed.

Science is easy! Once you remove the need for honesty that is.



Try some of the other **msa** tools offered by the **EBI**. Note the differences in the alignments computed. These differences are important and are not just the result of different parameters applied to exactly the same algorithms. Alignments are generated for different purposes in a variety of subtly different ways. A full consideration of **msa** is beyond the scope of these exercises¹¹⁴.

¹¹⁴ We do run specialist training in the generation and interpretation of **multiple sequence alignments** in Cambridge however. All are welcome.

PSI-BLAST

This program is used to find a comprehensive set of relatives of a protein. First, **BLAST** is used to find closely related proteins. From an alignment of these proteins a general "profile" (a Position Specific Scoring Matrix - **PSSM**) is computed. A **PSSM** is very similar in concept and purpose to an **HMM** profile in that it summarises significant features present in the sequences it represents.

A query against the protein database is then run using the **PSSM**, and a larger more widely associated group of proteins is found. This larger group is used to construct another **PSSM**, and the process is repeated until no more significantly matching new sequences can be detected, or the user tires of the whole process.

You have used **PSI-BLAST** integrated into **Jpred** already and similar ideas were used to create the **PFAM** alignments. Here we will use **PSI-BLAST** explicitly at the **NCBI** on the **Paired DOMAIN** of the **PAX6** protein that you saved in a file earlier. It should be possible to detect a large family of **PAX** domains and to eventually multiply align them generating something like the **Full** alignment from the **PFAM** database viewed earlier¹¹⁵.

To investigate **PSI-BLAST** go first to the **NCBI** Home page at:

<http://www.ncbi.nlm.nih.gov/>

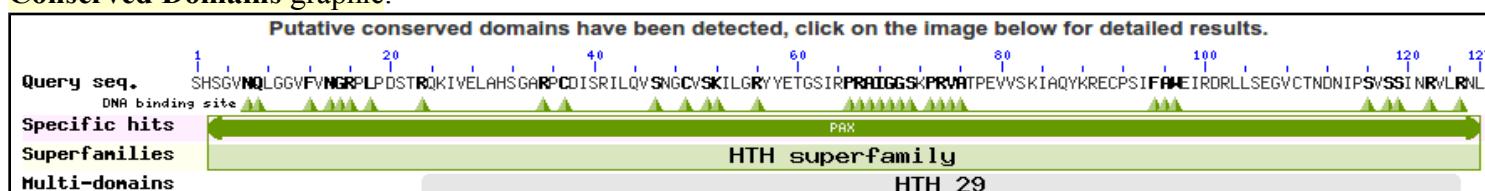
Click on the **BLAST** option. Select **protein BLAST** from the **Basic BLAST** section. Upload the **PAX6** paired box domain sequence (stored in the file **pax_domain.fasta**) using the appropriate **Browse** button.

Select **PSI-BLAST** from the **Program Selection** section. Leave all the others options at their default settings, particularly the option to search all the proteins available.

Before you set **PSI-BLAST** going, click on the **Algorithm parameters** link and take a look at the **PSI/PHI/DELTA BLAST** section. Here is offered the option to use a **PSSM** from a previous run **PSI-BLAST**, potentially on a different database (but with the same query sequence). Accept the default that database entries scoring better than an **Expect Threshold** of **0.005** be offered for inclusion into the **PSSM** of each successive **PSI-BLAST** iteration. Remember the **?** buttons.

What do you suppose the choice of **Pseudocount** might influence? _____

Elect to **Show results in a new window** and then click on the **BLAST** button. After several moments of deep thought, **PSI-BLAST** will come back with its first set of results, at the top of which is a report that (unsurprisingly) matches have been detected between the query sequence and several domain databases. For more detail, click on the **Conserved Domains** graphic.



¹¹⁵ But hopefully a mite more credible!

SMART, Pfam and the NCBI Conserved Domains database hits are reported. None should be a surprise.

Conserved domains on [Icl|Query_2485]

Pax-Domain P26367(4-130)

Graphical summary **Zoom to residue level** [show extra options >](#) [?](#)

Search for similar domain architectures [?](#) **Refine search** [?](#) [?](#)

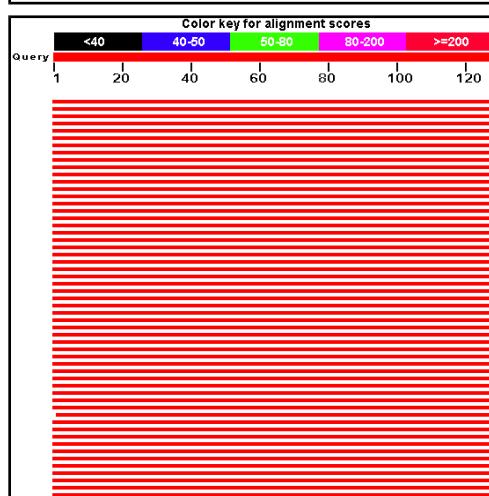
| List of domain hits | | Description | Interval | E-value |
|----------------------------|---------------|---|-----------------|----------------|
| [+] | PAX | cd00131 Paired Box domain | 2-127 | 5.03e-80 |
| [+] | PAX | smart00351 Paired Box domain; | 1-125 | 2.30e-81 |
| [+] | PAX | pfam00292 'Paired box' domain; | 1-125 | 2.38e-81 |
| [+] | HTH_29 | pfam13551 Winged helix-turn-helix; This helix-turn-helix domain is often found in transferases and is ... | 23-125 | 1.15e-04 |

Blast search parameters

Data Source: Live blast search RID = XCKC805Y014
User Options: Database: CDSEARCH/cdd v3.14 Low complexity filter: no Composition Based Adjustment: yes E-value threshold: 0.01 Maximum number of hits: 500

References:

- Marchler-Bauer A et al. (2015), "CDD: NCBI's conserved domain database.", *Nucleic Acids Res.* 43(D)222-6.
- Marchler-Bauer A et al. (2011), "CDD: a Conserved Domain Database for the functional annotation of proteins.", *Nucleic Acids Res.* 39(D)225-9.
- Marchler-Bauer A et al. (2009), "CDD: specific functional annotation with the Conserved Domain Database.", *Nucleic Acids Res.* 37(D)205-10.
- Marchler-Bauer A, Bryant SH (2004), "CD-Search: protein domain annotations on the fly.", *Nucleic Acids Res.* 32(W)327-331.



Moving back to the main **PSI-BLAST** results, you will see that there are many high quality hits covering the whole length of the query sequence.

Sequences producing significant alignments with E-value BETTER than threshold

Select: All None Selected:0

[Alignments](#) [Download](#) [GenPept](#) [Graphics](#) [Distance tree of results](#) [Multiple alignment](#) [?](#)

| | Description | Max score | Total score | Query cover | E value | Ident | Accession | Select for PSI to build blast PSSM |
|--------------------------|--|-----------|-------------|-------------|---------|-------|----------------|-------------------------------------|
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X4 [Macaca nemestrina] | 262 | 262 | 100% | 1e-83 | 100% | XP_011722295.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Ursus maritimus] | 263 | 263 | 100% | 1e-83 | 100% | XP_008685073.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | oculorhombin [Homo sapiens] | 263 | 263 | 100% | 1e-83 | 100% | AAA59962.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | paired box protein Pax-6 [Rattus norvegicus] | 263 | 263 | 100% | 1e-83 | 100% | NP_037133.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Fukomys damarensis] | 263 | 263 | 100% | 1e-83 | 100% | XP_010638711.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Cavia porcellus] | 263 | 263 | 100% | 1e-83 | 100% | XP_003464531.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Aotus nancymaae] | 263 | 263 | 100% | 1e-83 | 100% | XP_012307699.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Callorhinus milii] | 263 | 263 | 100% | 1e-83 | 100% | XP_007885973.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Heterocephalus glaber] | 263 | 263 | 100% | 1e-83 | 100% | XP_004851665.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 isoform X2 [Octodon degus] | 263 | 263 | 100% | 1e-83 | 100% | XP_004638029.1 | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> | PREDICTED: paired box protein Pax-6 [Poecilia reticulata] | 261 | 261 | 100% | 1e-83 | 98% | XP_008404092.1 | <input checked="" type="checkbox"/> |

The best **500** of these are listed.

All the listed hits are selected for inclusion into the **PSSM** for the next iteration. Unless you feel strongly about any particular entry, leave them all selected.

Download ▾ GenPept Graphics

oculorhombin [Homo sapiens]
Sequence ID: [gb|AA59962.1](#) Length: 422 Number of Matches: 1

Range 1: 4 to 130 GenPept Graphics ▾ Next Match ▲ Previous Match

| Score | Expect | Method | Identities | Positives | Gaps |
|---------------|--|--|---------------|---------------|-----------|
| 263 bits(671) | 1e-83 | Compositional matrix adjust. | 127/127(100%) | 127/127(100%) | 0/127(0%) |
| <hr/> | | | | | |
| Query 1 | SHSGVNOLGGVFVNGRPLPDSTROKIVELAHS...
Sbjct 4 | SHSGVNOLGGVFVNGRPLPDSTROKIVELAHS... | 60 | | |
| Query 61 | GSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
Sbjct 64 | GSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
GSIRPRAIGGSKPRVATPEVSKIAQYKRECP... | 120 | | |
| Query 121 | NRVLRLN 127
NRVLRLN | NRVLRLN 127
NRVLRLN | 127 | | |
| Sbjct 124 | NRVLRLN 130 | | 130 | | |

Download ▾ GenPept Graphics

paired box protein Pax-6 [Rattus norvegicus]
Sequence ID: [ref|NP_037133.1](#) Length: 422 Number of Matches: 1
► See 3 more title(s)

Range 1: 4 to 130 GenPept Graphics ▾ Next Match ▲ Previous Match

| Score | Expect | Method | Identities | Positives | Gaps |
|---------------|--|--|---------------|---------------|-----------|
| 263 bits(671) | 1e-83 | Compositional matrix adjust. | 127/127(100%) | 127/127(100%) | 0/127(0%) |
| <hr/> | | | | | |
| Query 1 | SHSGVNOLGGVFVNGRPLPDSTROKIVELAHS...
Sbjct 4 | SHSGVNOLGGVFVNGRPLPDSTROKIVELAHS... | 60 | | |
| Query 61 | GSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
Sbjct 64 | GSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
GSIRPRAIGGSKPRVATPEVSKIAQYKRECP... | 120 | | |
| Query 121 | NRVLRLN 127
NRVLRLN | NRVLRLN 127
NRVLRLN | 127 | | |
| Sbjct 124 | NRVLRLN 130 | | 130 | | |

Move down to the Alignments section of the results and you will see that many of the top hits match the query exactly.

Note that many of the top hits come from the GenPept database (roughly equivalent to the TrEMBL section of UniProtKB).

How might the inclusion of relatively poor quality sequences and the presence of so much duplication have been minimised?

Download ▾ GenPept Graphics ▾ Next ▲ Previous ▲ Descriptions

paired box protein Pax-6 [Xenopus laevis]
Sequence ID: [ref|NP_001165666.1](#) Length: 393 Number of Matches: 1
► See 1 more title(s)

Range 1: 4 to 130 GenPept Graphics ▾ Next Match ▲ Previous Match

| Score | Expect | Method | Identities | Positives | Gaps |
|---------------|--|--|--------------|--------------|-----------|
| 259 bits(661) | 2e-82 | Compositional matrix adjust. | 125/127(98%) | 126/127(99%) | 0/127(0%) |
| <hr/> | | | | | |
| Query 1 | SHSGVNQLGGVFVNGRPLPDSTROKIVELAHS...
Sbjct 4 | SHSGVNQLGGVFVNGRPLPDSTROKIVELAHS... | 60 | | |
| Query 61 | GSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
Sbjct 64 | GSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
GSIRPRAIGGSKPRVATPEVSKIAQYKRECP... | 120 | | |
| Query 121 | NRVLRLN 127
NRVLRLN | NRVLRLN 127
NRVLRLN | 127 | | |
| Sbjct 124 | NRVLRLN 130 | | 130 | | |

Download ▾ GenPept Graphics ▾ Next ▲ Previous ▲ Descriptions

Pax6 [Bos taurus]
Sequence ID: [gb|AAC18658.1](#) Length: 146 Number of Matches: 1

Range 1: 4 to 144 GenPept Graphics ▾ Next Match ▲ Previous Match

| Score | Expect | Method | Identities | Positives | Gaps |
|---------------|--|--|--------------|--------------|------------|
| 250 bits(638) | 2e-82 | Compositional matrix adjust. | 127/141(90%) | 127/141(90%) | 2e-141(9%) |
| <hr/> | | | | | |
| Query 1 | SHSGVNOLGGVFVNGRPLPDSTROKIVELAHS...
Sbjct 4 | SHSGVNOLGGVFVNGRPLPDSTROKIVELAHS... | VS | 46 | |
| Query 47 | NGCVSKILGRYYETGSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
Sbjct 64 | NGCVSKILGRYYETGSIRPRAIGGSKPRVATPEVSKIAQYKRECP...
NGCVSKILGRYYETGSIRPRAIGGSKPRVATPEVSKIAQYKRECP... | 106 | | |
| Query 107 | GVCTNDNIPSVSSINRVLRLN 127
GVCTNDNIPSVSSINRVLRLN | GVCTNDNIPSVSSINRVLRLN 127
GVCTNDNIPSVSSINRVLRLN | 127 | | |
| Sbjct 124 | GVCTNDNIPSVSSINRVLRLN 144 | | 144 | | |

Move down far enough and you will see less perfect matches, some of which involve proteins with the extra 14 amino acids of **isoform 5a of PAX6_HUMAN**.

Having browsed your results sufficiently, click on the **Go** button to **Run PSI-Blast iteration 2**. It is at the bottom of the hit list.

| | | | | | | | | |
|--|-----|-----|-----|-------|-----|----------------|-------------------------------------|-------------------------------------|
| <input type="checkbox"/> paired box 6 [Monodelphis domestica] | 238 | 238 | 94% | 7e-76 | 90% | ACZ54379.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> PREDICTED: paired box protein Pax-6-like isoform X1 [Acromyrmex ec] | 246 | 246 | 99% | 8e-76 | 94% | XP_011063177.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> putative paired box protein pax-6 [Schistosoma mansoni] | 254 | 254 | 99% | 1e-75 | 90% | CCD79466.1 | <input checked="" type="checkbox"/> | |
| <input type="checkbox"/> putative Paired box protein Pax-6 [Operophtera brumata] | 232 | 232 | 90% | 1e-75 | 97% | KOB68243.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> twin of eyeless [Bombix mori] | 234 | 234 | 94% | 1e-75 | 89% | NP_001189460.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> PREDICTED: eyeless isoform X3 [Tribolium castaneum] | 242 | 242 | 99% | 2e-75 | 91% | XP_008192001.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> PREDICTED: eyeless isoform X2 [Tribolium castaneum] | 242 | 242 | 99% | 2e-75 | 91% | XP_008192000.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> PREDICTED: paired box protein Pax-6-like isoform X1 [Megachile rotundata] | 245 | 245 | 99% | 2e-75 | 94% | XP_012148240.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> Hypothetical protein CBG04481 [Caenorhabditis briggsae] | 239 | 239 | 99% | 2e-75 | 82% | XP_002644124.1 | <input checked="" type="checkbox"/> | |
| <input type="checkbox"/> pax6-like protein [Euperipatoides kanangrensis] | 233 | 233 | 92% | 3e-75 | 95% | AGC51117.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> paired box protein Pax-6 [Clonorchis sinensis] | 251 | 251 | 99% | 3e-75 | 90% | GAA48050.1 | <input checked="" type="checkbox"/> | |
| <input type="checkbox"/> PREDICTED: paired box protein Pax-6-like [Amyelois transitella] | 231 | 231 | 91% | 3e-75 | 92% | XP_013196296.1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| <input type="checkbox"/> hypothetical protein T265_09221 [Opisthorchis viverrini] | 251 | 251 | 99% | 3e-75 | 90% | XP_009173504.1 | <input checked="" type="checkbox"/> | |

After a few moments, **PSI-BLAST** will return with the results of searching through the database again using the **PSSM** derived from the hits of the first iteration(d). This time the top of the list will be predominantly filled with hits that have already been incorporated into the **PSI-BLAST PSSM**. However, look far enough down the list and you will find some new ones, highlighted yellow.

Once more, click on the **Go** button to **Run PSI-Blast iteration 3**. That is probably enough! It took 4 iterations before there were no more new sequences suggested for inclusion into the **PSMM** when I ran this last, so if you really want to take things to their logical conclusion, it should not detain you long.

Next, move to the top of the **Descriptions** list and **Select All**. Click on the **Multiple Alignment** button. You have elected to use the **NCBI** multiple alignment program **Cobalt** to align all the **PAX** domain sequences of your final **PSI-BLAST** iteration that match with an **Expect** score better than **0.001**. In an impressively short time, your alignment will appear.

Move past the long list of proteins that have been aligned (the easiest way is to hide the **Descriptions** view).

At the top of the actual alignment, set **View Format** to **Plain Text** (.... and then hide the **Descriptions** again??), this being the easiest format to understand in a hurry. The alignment will have very ragged ends, but the important region of **120** or so amino acids representing the **PAX** domain is really quite impressive. In particular, the **isoform 5a** insertion is very convincing¹¹⁶.

| | | | |
|--|----|---|-----|
| <input checked="" type="checkbox"/> XP_003977912 | 52 | TRQKIVELAHSGARPCDISRILQTHDA--VQVLDSKEV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 114 |
| <input checked="" type="checkbox"/> XP_009296159 | 26 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNENV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 90 |
| <input checked="" type="checkbox"/> XP_003246075 | 54 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIKPRAIGGSK | 104 |
| <input checked="" type="checkbox"/> XP_012793883 | 41 | TRQRITELAHSGARPCDISRILQ-----V-----SNGCVSKILC---RYYETGSIRPKAIGGSK | 91 |
| <input checked="" type="checkbox"/> XP_005991286 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDIQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> EFX75780 | 37 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 87 |
| <input checked="" type="checkbox"/> ABB43131 | 25 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 75 |
| <input checked="" type="checkbox"/> ETN66652 | 41 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIKPRAIGGSK | 91 |
| <input checked="" type="checkbox"/> XP_006128959 | 56 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 120 |
| <input checked="" type="checkbox"/> XP_010874560 | 44 | TRQKIVELAHSGARPCDISRILQTHDDSKVQVLDNENV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 108 |
| <input checked="" type="checkbox"/> AFJ24746 | 53 | TRQRIVELAHSGARPCDISRILQ-----V-----SNGCVSKILC---RYYETGSIRPKAIGGSK | 103 |
| <input checked="" type="checkbox"/> XP_007885968 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVVDNRKV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> BAA24024 | 42 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDSQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 106 |
| <input checked="" type="checkbox"/> XP_012307695 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> CBY09679 | 55 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILA---RYYETGSIKPRAIGGSK | 105 |
| <input checked="" type="checkbox"/> XP_007181079 | 82 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 146 |
| <input checked="" type="checkbox"/> CAF29075 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDSENV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_004264009 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_009184622 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> AAW24017 | 55 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILA---RYYETGSIKPRAIGGSK | 105 |
| <input checked="" type="checkbox"/> XP_008547741 | 26 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 76 |
| <input checked="" type="checkbox"/> XP_012162452 | 50 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIKPRAIGGSK | 100 |
| <input checked="" type="checkbox"/> XP_006975926 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNENV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> KDR14710 | 21 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 71 |
| <input checked="" type="checkbox"/> XP_005530321 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> ABI98847 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_010794780 | 44 | TRQKIVELAHSGARPCDISRILQTHD--VQVLDSKEV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 106 |
| <input checked="" type="checkbox"/> NP_001103907 | 26 | TRQKIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 76 |
| <input checked="" type="checkbox"/> XP_010356630 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_010638709 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_005064878 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNENV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> NP_038655 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNENV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_005401829 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> XP_004638028 | 25 | TRQKIVELAHSGARPCDISRILQTHADAKVQVLDNQNV-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 89 |
| <input checked="" type="checkbox"/> BAM74254 | 32 | TRQRIVELAHSGARPCDISRILQ-----V-----SNGCVSKILG---RYYETGSIRPRAIGGSK | 82 |

¹¹⁶ Much more so than the **Full** alignment offered by **PFAM**, I would contend. Although, it has to be admitted, the **Pfam** alignment included more sequences and I suspect they would have gone for a less closely homologous set of sequences. Even so ... I think the alignment illustrated here is MUCH more beautiful!!

Protein Tertiary Structure

Protein Data Bank (PDB)

The **Protein Data Bank (PDB)** archive is the major repository of information about the 3D structures of biological molecules, including proteins and nucleic acids. Structures in the archive range from tiny proteins and bits of DNA to complex molecular machines like the ribosome.



In 1998, the **Research Collaboratory for Structural Bioinformatics (RCSB)** became responsible for the management of the **PDB**.

In 2003, the **wwwPDB** formed to maintain a single **PDB** archive of macromolecular structural data that is freely and publicly available to the global community. It consists of organizations that act as deposition, data processing and distribution centres for **PDB** data.



PDBe is the European resource for the collection, organisation and dissemination of data on biological macromolecular structures. In collaboration with the other Worldwide Protein Data Bank (**wwPDB**) and **EMDataBank** partners, they work to collate, maintain and provide access to the global repositories of macromolecular structure data (the Protein Data Bank (**PDB**) and Electron Microscopy Data Bank (**EMDB**)).



In the course of the exercises undertaken to this point, you will have already had a look at the 3D structures for the 2 major domains of the human **PAX6** protein. You might have taken a more direct route to these structures by asking for them directly from the **RCSB PDB** site as follows.

Go to:

<http://www.rcsb.org>

Enter **PAX6** in the **Search** box and click on the **Go** button.

Click on the link under the **Molecule Name** title..

PAX6

Gene View Molecule Name

close

• PAX6 - paired box 6 (2) • Paired box protein Pax6 (2)

Find all

Structural Domains Protein Feature View

• Paired... pax6... (1) • pax6...
 • pax6 - Oryzias latipes
 • pax6 - Homo sapiens (2)
 • pax6 - Gallus gallus
 • pax6...
 • pax6 - Xenopus laevis
[More](#)

| | |
|----------------|---|
| | CRYSTAL STRUCTURE OF THE HUMAN PAX-6 PAIRED DOMAIN-DNA COMPLEX REVEALS A GENERAL MODEL FOR PAX PROTEIN-DNA INTERACTIONS |
| Authors: | Xu, H.E., Roud, M.A., Xu, W., Epstein, J.A., Maas, R.L., Pabo, C.O. |
| Release: | 1999-07-13 |
| Experiment: | X-RAY DIFFRACTION with resolution of 2.50 Å |
| Residue Count: | 185 |
| Compound: | 3 Polymers [Display Full Polymer Details Display for All Results] |
| Citation: | Crystal structure of the human Pax6 paired domain-DNA complex reveals specific roles for the linker region and carboxy-terminal subdomain in DNA binding.
(1999) <i>Genes Dev.</i> 13 : 1263-1275 [Display Full Abstract Display for All Results] |

| | |
|----------------|--|
| | Solution structure of the homeobox domain of the human paired box protein Pax-6 |
| Authors: | Ohnishi, S., Kigawa, T., Tochio, N., Tonizawa, T., Koshiba, S., Inoue, M., Yokoyama, S., RIKEN Structural Genomics/Proteomics Initiative |
| Release: | 2005-11-26 |
| Experiment: | SOLUTION NMR |
| Residue Count: | 80 |
| Compound: | 1 Polymer [Display Full Polymer Details Display for All Results] |
| Citation: | PubMed ID is not available. |

Take a look at the **Jmol** view of the **6PAX PDB** entry. This you have seen this previously, but now I suggest a very quick visualisation of the main mutation that causes aniridia occurs in the **PAX** protein. The idea is to locate and highlight the **Alanine** that mutates to a **Proline** in an aniridia sufferer. As you have discovered, this is the residue **33** in the canonical protein, as recorded by **UniProtKB**. It is residue **30** in the protein as visualised here, the difference being explained by **post translational modification** which, in this instance, removes the first three amino acids.

Instructions for using **Jmol** can be found in many places. For a **Quick Guide**, you might try:

<http://blc.arizona.edu/courses/mcb184/graphics/JmolQuickReferenceSheet.pdf>

One place for the full manual is:

<http://jmol.sourceforge.net/docs/JmolUserGuide/>

Please note **Jmol** is not the only structure visualisation option available to you, nor is it the most sophisticated. It is just the one used by **PDB**. Here we look at just the minimum of **Jmol** skills to see what is required. First notice you can zoom in and out with the wheel of your mouse. You can also rotate the image in all directions using your left hand mouse button. Use these two tricks as needed.

To proceed any further, you really need a console window into which you can type commands. To get a console, choose **Console**. From the right hand mouse button pull down menu.

In the lower section of the console, select the **30th** amino acid with the command:

select 30

Then to make the selected residue more evident, type in the two commands:

spacefill

color cyan

and then manipulate the structure until the selected amino acid can be best observed.



LJM/DPJ/PDFJ 2015.08.23

This page is “Work in progress”

As SCOP and CATH still crop up, I wish to include them, probably as an extra exercise.

Also maybe some other structure discussion I am not really qualified to write?

This is just some remnants left over from previous versions.

Structural Classification of Proteins (SCOP)



The Structural Classification Of Proteins (SCOP) database is a largely manual hierarchical classification of protein structural domains based on similarities of their amino acid sequences and three-dimensional structures.

For a quick look at SCOP, go to:

<http://scop.mrc-lmb.cam.ac.uk/scop/>

You could go directly to all SCOP has to offer concerning PAX proteins by using a **Keyword search of SCOP entries**. For a better view of the way SCOP is structured, click on the **top of the hierarchy link**.

The top level SCOP classifications is listed. It should be possible to view sample structures for each class, but your browser is unlikely to be suitably configured¹¹⁷, so instead, click on the **All alpha proteins** link¹¹⁸.

Next, the **DNA/RNA binding 3-helical bundle** category looks the most tempting, so click it. From here options abound! **Homeodomain-like** has appeal, but **“Winged helix” DNA-dinding domain** suggests so much more adventure. Either/both works. You decide which way to descend down SCOP's hierarchy. Note the opportunities to branch off to other relevant databases.

Classes:

1. [All alpha proteins](#) [46456] (284)
2. [All beta proteins](#) [48724] (174)
3. [Alpha and beta proteins \(a/b\)](#) [51349] (147)
Mainly parallel beta sheets (*beta-alpha-beta units*)
4. [Alpha and beta proteins \(a+b\)](#) [53931] (376)
Mainly antiparallel beta sheets (*segregated alpha and beta regions*)
5. [Multi-domain proteins \(alpha and beta\)](#) [56572] (66)
Folds consisting of two or more domains belonging to different classes
6. [Membrane and cell surface proteins and peptides](#) [56835] (58)
Does not include proteins in the immune system
7. [Small proteins](#) [56992] (90)
Usually dominated by metal ligand, heme, and/or disulfide bridges
8. [Coiled coil proteins](#) [57942] (7)
Not a true class
9. [Low resolution protein structures](#) [58117] (26)
Not a true class
10. [Peptides](#) [58231] (121)
Peptides and fragments. Not a true class
11. [Designed proteins](#) [58788] (44)
Experimental structures of proteins with essentially non-natural sequences. Not a true class

¹¹⁷ You need either **rasmol** and/or **Chime** to be suitably configured. Both are good, but obsolete, structure viewers.

¹¹⁸ Well ... they were not very big beta sheets!

Appendix I: Sequence symbols

Nucleotide symbols, their complements, and the standard one-letter amino acid symbols are shown below in separate lists. The letter codes for amino acid codes and nucleotide ambiguity were proposed by IUB (Nomenclature Committee, 1985, Eur. J. Biochem. 150; 1-5)

NUCLEOTIDES

The meaning of each symbol and its complement are shown below.

| IUB/GCG | Meaning | Complement |
|---------|----------------------|------------|
| A | A | T |
| C | C | G |
| G | G | C |
| T/U | T | A |
| M | A or C | K |
| R | A or G | Y |
| W | A or T | W |
| S | C or G | S |
| Y | C or T | R |
| K | G or T | M |
| V | A or C or G | B |
| H | A or C or T | D |
| D | A or G or T | H |
| B | C or G or T | V |
| X/N | G or A or T or C | X |
| . | not G or A or T or C | . |

AMINO ACIDS

Here the standard one and three letter amino acid codes, synonymous codons and IUB codes are shown. Codons following semicolons (;) are not sufficiently specific to define a single amino acid even though they represent the best possible back-translation into the IUB codes!

Amino Acid NOTATION

| Symbol | 3-letter | Meaning | Codons | IUB Depiction |
|--------|----------|----------------------|------------------------------|---------------------------------|
| A | Ala | Alanine | GCT, GCC, GCA, GCG | !GCX |
| B | Asp, Asn | Aspartic, Asparagine | GAT, GAC, AAT, AAC | !RAY |
| C | Cys | Cysteine | TGT, TGC | !TGY |
| D | Asp | Aspartic | GAT, GAC | !GAY |
| E | Glu | Glutamic | GAA, GAG | !GAR |
| F | Phe | Phenylalanine | TTT, TTC | !TTY |
| G | Gly | Glycine | GGT, GGC, GGA, GGG | !GGX |
| H | His | Histidine | CAT, CAC | !CAY |
| I | Ile | Isoleucine | ATT, ATC, ATA | !ATH |
| K | Lys | Lysine | AAA, AAG | !AAR |
| L | Leu | Leucine | TTG, TTA, CTT, CTC, CTA, CTG | !TTR, CTX, YTR; YT _X |
| M | Met | Methionine | ATG | !ATG |
| N | Asn | Asparagine | AAT, AAC | !AAY |
| P | Pro | Proline | CCT, CCC, CCA, CCG | !CCX |
| Q | Gln | Glutamine | CAA, CAG | !CAR |
| R | Arg | Arginine | CGT, CGC, CGA, CGG, AGA, AGG | !CGX, AGR, MGR; MG _X |
| S | Ser | Serine | TCT, TCC, TCA, TCG, AGT, AGC | !TCX, AGY; WSX |
| T | Thr | Threonine | ACT, ACC, ACA, ACG | !ACX |
| V | Val | Valine | GTT, GTC, GTA, GTG | !GTX |
| W | Trp | Tryptophan | TGG | !TGG |
| X | Xxx | Unknown | | !XXX |
| Y | Tyr | Tyrosine | TAT, TAC | !TAY |
| Z | Glu, Gln | Glutamic, Glutamine | GAA, GAG, CAA, CAG | !SAR |
| * | End | Terminator | TAA, TAG, TGA | !TAR, TRA; TRR |

Appendix II: Sequence comparison scoring matrices

Default EMBOSS DNA Scoring Matrix.

| | A | T | G | C | S | W | R | Y | K | M | B | V | H | D | N | U |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| A | 5 | -4 | -4 | -4 | -4 | 1 | 1 | -4 | -4 | 1 | -4 | -1 | -1 | -1 | -2 | -4 |
| T | -4 | 5 | -4 | -4 | -4 | 1 | -4 | 1 | 1 | -4 | -1 | -4 | -1 | -1 | -2 | 5 |
| G | -4 | -4 | 5 | -4 | 1 | -4 | 1 | -4 | 1 | -4 | -1 | -1 | -4 | -1 | -2 | -4 |
| C | -4 | -4 | -4 | 5 | 1 | -4 | -4 | 1 | -4 | 1 | -1 | -1 | -1 | -4 | -2 | -4 |
| S | -4 | -4 | 1 | 1 | -1 | -4 | -2 | -2 | -2 | -2 | -1 | -1 | -3 | -3 | -1 | -4 |
| W | 1 | 1 | -4 | -4 | -4 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -1 | -1 | 1 | |
| R | 1 | -4 | 1 | -4 | -2 | -2 | -1 | -4 | -2 | -2 | -3 | -1 | -3 | -1 | -1 | -4 |
| Y | -4 | 1 | -4 | 1 | -2 | -2 | -4 | -1 | -2 | -2 | -1 | -3 | -1 | -3 | -1 | 1 |
| K | -4 | 1 | 1 | -4 | -2 | -2 | -2 | -1 | -4 | -1 | -3 | -3 | -1 | -1 | 1 | |
| M | 1 | -4 | -4 | 1 | -2 | -2 | -2 | -2 | -4 | -1 | -3 | -1 | -1 | -3 | -1 | -4 |
| B | -4 | -1 | -1 | -1 | -1 | -3 | -3 | -1 | -1 | -3 | -1 | -2 | -2 | -2 | -1 | -1 |
| V | -1 | -4 | -1 | -1 | -1 | -3 | -1 | -3 | -3 | -1 | -2 | -1 | -2 | -2 | -1 | -4 |
| H | -1 | -1 | -4 | -1 | -3 | -1 | -3 | -1 | -3 | -1 | -2 | -2 | -1 | -2 | -1 | -1 |
| D | -1 | -1 | -1 | -4 | -3 | -1 | -1 | -3 | -1 | -3 | -2 | -2 | -2 | -1 | -1 | -1 |
| N | -2 | -2 | -2 | -2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -2 |
| U | -4 | 5 | -4 | -4 | -4 | 1 | -4 | 1 | 1 | -4 | -1 | -4 | -1 | -1 | -2 | 5 |

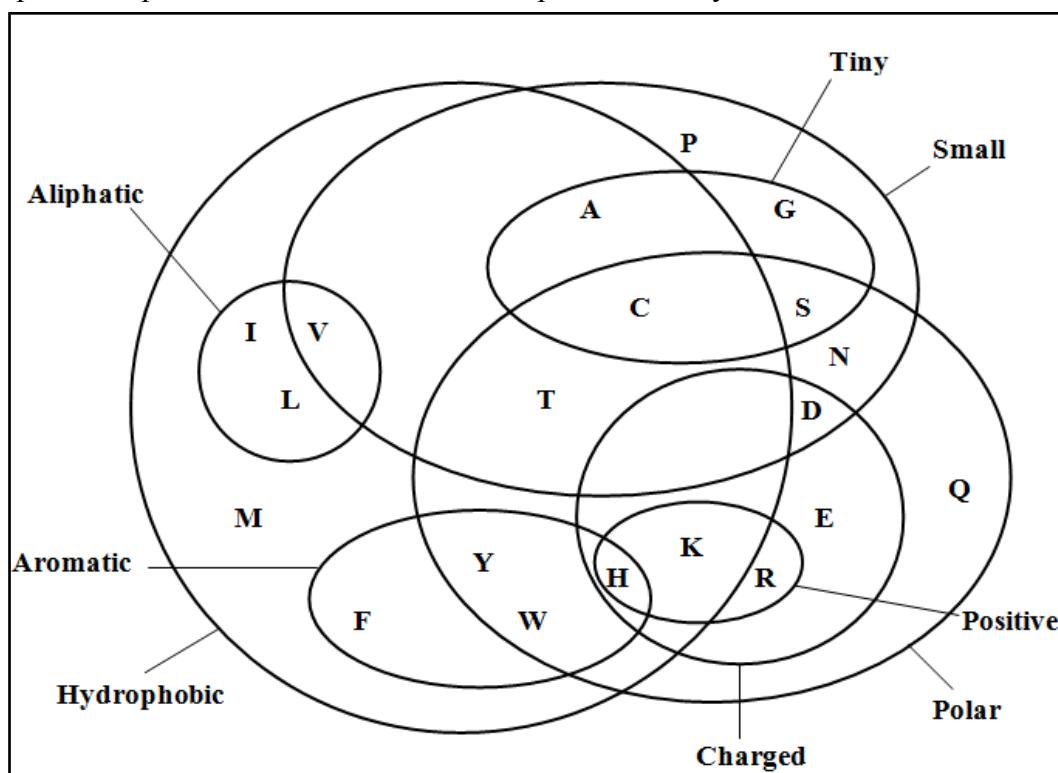
Appendix III: list files

A list file is a text file of sequence file names or database references. It is an excellent and flexible way for you to produce a specific mini-database, e.g. to do *fasta* searches against or look for patterns in. Each entry is on a separate line. These can be sequences either in your Unix account, in a sequence database or even in another list file. You can even put in comments if you preface them with an exclamation mark (!). The @ symbol in front of your list file tells EMBOSS programs that the file is a file of filenames and not a sequence. For example:

```
seqret @listfile
embl:hsfau      ! an entry in the embl database
rabbit.seq       ! a file in your directory
swissprot:pax6*  ! all SwissProt entries whose identifier starts with "pax6"
@hedgehog.list   ! another list file called "hedgehog.list"
```

Appendix IV: Amino Acid Properties

Amino acid properties important in the determination of protein tertiary structure.



A quick look at OMIM

OMIM is the **Online** version of Victor McKusick's **Mendelian Inheritance in Man**. It is a database of human disease phenotypes, with a substantial genetic component. There are many ways to get to the **OMIM** entries relating to **aniridia** and **PAX6**, including directly from the **PAX6 GeneCard**.

Jump to the Disorders section.

The first **OMIM** link ([607108](#)) is to the gene **PAX6** entry. There are other **OMIM** links for **PAX6** disorders, including one for **Aniridia** ([106210](#)).

OMIM: [607108](#) **disorders:** [106210](#) [604229](#) [604219](#) [148190](#) [136520](#) [120430](#) [165550](#) [120200](#) [206700](#)

UniProtKB/Swiss-Prot: [PAX6_HUMAN](#), P26367

- Defects in PAX6 are the cause of aniridia (AN) [MIM:106210]. A congenital, bilateral, panocular disorder characterized by complete absence of the iris or extreme iris hypoplasia. Aniridia is not just an isolated defect in iris development but it is associated with macular and optic nerve hypoplasia, cataract, corneal changes, nystagmus. Visual acuity is generally low but is unrelated to the degree of iris hypoplasia. Glaucoma is a secondary problem causing additional visual loss over time

Click on the **Aniridia** link. Here the **Gene map locus** is confirmed. Click on the **Location** link for the **OMIM** map of Chromosome 11 around **PAX6**¹¹⁹. You will see a fuller representation in **Ensembl** later.

| Location
(genomic start,
cyto location)
<small>(from NCBI)</small> | Gene/Locus | Gene/Locus name | Gene/Locus
MIM
number | Phenotype | Phenotype
MIM
number | Pheno
map
key | Comments | Mouse
symbol
<small>(from MGd)</small> |
|---|--------------------|--|-----------------------------|--|--|--|----------|--|
| 11:31,284,170
11p13 | DCDC1 | Doublecortin domain-containing protein 1 | 608062 | | | | | |
| 11:31,391,376
11p13 | DPH4 | DPH4, <i>S. cerevisiae</i> , homolog of | 611072 | | | | | Dnajc24 |
| 11:31,453,948
11p13 | IMMP1L,
IMP1 | Inner mitochondrial membrane peptidase, subunit 1, <i>S. cerevisiae</i> , homolog of | 612323 | | | | | Immp1l |
| 11:31,531,296
11p13 | ELP4,
PAX6NEB | Elongation protein 4, <i>S. cerevisiae</i> , homolog of | 606985 | | | | | Elp4 |
| 11:31,806,339
11p13 | PAX6, AN2,
MGDA | Paired box homeotic gene-6 | 607108 | Aniridia
Cataract with late-onset corneal dystrophy
Coloboma of optic nerve
Coloboma, ocular
Foveal hyperplasia
Gillespie syndrome
Keratitis
Morning glory disc anomaly
Optic nerve hypoplasia
Peters anomaly | 106210
106210
120430
120200
136520
206700
148190
120430
165550
604229 | 3
3
3
3
3
3
3
3
3
3 | | Pax6 |

Move back to the **aniridia** **OMIM** entry and follow the link to the **OMIM** entry for **PAX6** ([607108](#)) which you will find in the **TEXT** section. From the **Table of Contents** menu, select **Allelic Variants**. Click on **Table View**.

| PAIRED BOX GENE 6; PAX6 | | | |
|---------------------------------------|--|------------------------|---------------|
| Allelic Variants (Selected Examples): | | | |
| Number | Phenotype | Mutation | dbSNP |
| .0001 | ANIRIDIA | PAX6, 2-BP INS | - |
| .0002 | ANIRIDIA | PAX6, EXON G DEL | - |
| .0003 | ANIRIDIA | PAX6, GLN116TER | [rs121907912] |
| .0004 | PETERS ANOMALY
ANIRIDIA, INCLUDED | PAX6, ARG26GLY | [rs121907913] |
| .0005 | ANIRIDIA | PAX6, ARG103TER | [rs121907914] |
| .0006 | CATARACTS, CONGENITAL, WITH LATE-ONSET CORNEAL DYSTROPHY | PAX6, SER353TER | [rs121907915] |
| .0007 | ANIRIDIA | PAX6, IVS12DS, G-C, -1 | - |
| .0008 | ANIRIDIA | PAX6, ARG203TER | [rs121907916] |
| .0009 | ANIRIDIA | PAX6, ARG240TER | [rs121907917] |
| .0010 | ANIRIDIA | PAX6, IVS11AS, A-G, -2 | - |
| .0011 | KERATITIS, AUTOSOMAL DOMINANT | PAX6, IVS10AS, A-T, -2 | - |
| .0012 | FOVEAL HYPOPLASIA, ISOLATED | PAX6, ARG125CYS | [rs121907918] |
| .0013 | ANIRIDIA, ATYPICAL | PAX6, VAL126ASP | [rs121907919] |
| .0014 | FOVEAL HYPOPLASIA AND PRESENILE CATARACT SYNDROME | PAX6, GLY64VAL | [rs121907920] |

Several variants of this protein causing **aniridia** are listed, many are associated with a **dbSNP** entry, none of which is the one we will be investigating. As is admitted, the list is just selected examples¹²⁰

What do you notice about all the variants that are associated with a **dbSNP** entry?

Does this surprise you?

119 Note the way you can move along the Chromosome map. I went **Forward 3** entries to get my picture.

120 The full (known) list (and much more) is available in a database specific to human **PAX6** allelic variants. This can be found at:
<http://lsdb.hgu.mrc.ac.uk/>



Other databases from the European Bioinformatics Institute (EBI)

In a new browser window, go to the **EBI** homepage:

<http://www.ebi.ac.uk>

For this exercise, you started to investigate **aniridia** at the **Genecards** site in Israel. There are many alternative starting points, including the **EBI**¹²¹, where many of the databases you have been browsing are maintained, or at least mirrored. The **EBI** is not restricted to any particular organism and so would be a better choice for inquiries that are not specific to *Homo Sapiens*. The resources available for searching are displayed just underneath the search box.

You have already discovered much about **anirida**, certainly enough to consider using the **PAX6** protein accession code **P26367** as a search term. However, if you were really starting from the beginning, you would more probably be inclined to type the keyword **aniridia** into the **Explore the EBI** box and click the **Search** button.

Explore the EBI:
aniridia
Examples: blast, keratin, bfl1...

The **EBI Search** finds matches to **aniridia** with the many entries in the many databases of the **EBI**. Take a quick look at the hit list that is generated. From here, this exercise might divert in a numerous directions. For now, the focus is still the **PAX6** human protein. So, **Filter your results** to show just the **Protein sequences**.

Organisms

- Homo sapiens** (11)
- Ambystoma mexicanum* (4)
- Tetraodon nigroviridis* (2)
- Mus musculus* (1)
- Drosophila melanogaster* (1)
- Macaca fascicularis* (1)
- Canis lupus familiaris* (1)
- Sus scrofa* (1)

Filter your results
Source

- All results (1,270)
- Nucleotide sequences (39)
- Protein sequences (22)
- Macromolecular structures (3)
- Molecular interactions (1)
- Reactions, pathways & diseases (43)
- Protein families (2)
- Literature (1,158)
- EBI web (2)

Further refine your list by specifying just the **Organism Homo sapiens**.

Protein sequences (11 results found)

PAX6_HUMAN (P26367...)

Paired box protein Pax-6
Homo sapiens (Reviewed)

Related data ▾ Views ▾

Source: UniProtKB
ID: PAX6_HUMAN

Summary information is available for this protein

At the top of your list, you should not be surprised to see **PAX6_HUMAN**.

Related data ▾ Views ▾
This entry has references in

- [Genomes](#)
- [Nucleotide sequences](#)
- [Protein sequences](#)
- [Macromolecular structures](#)
- [Small molecules](#)
- [Gene expression](#)
- [Molecular interactions](#)
- [Reactions, pathways & diseases](#)
- [Protein families](#)
- [Literature](#)
- [Ontologies](#)

It is possible to link to the corresponding entries in other **EBI** databases. From the **Related data** pull down menu, select the **Ontologies** option.

Filter your results
Source

- Ontologies** (54)
- GO (53)
- Taxonomy (1)

Filter your results to include just entries from the **Gene Ontology (GO)** database.

Many of the entries found should cause you little surprise¹²².

| SEQUENCE-SPECIFIC DNA BINDING RNA POLYMERASE II TRANSCRIPTION FACTOR ACTIVITY | |
|--|--|
| Ontology: molecular function
Interacting selectively and non-covalently with a specific DNA sequence in order to modulate transcription by RNA polymerase II. The transcription factor may or may not also interact selectively with a protein or macromolecular complex. | Related data Views
Source: GO
ID: GO:0000981 |
| | |

Of course, you could find links to the same **GO** entries within the **UniprotKB** database entry.

| IRIS MORPHOGENESIS | |
|---|--|
| Ontology: biological process
The process in which the iris is generated and organized. The iris is an anatomical structure in the eye whose opening forms the pupil. The iris is responsible for controlling the diameter and size of the pupil and the amount of light reaching the retina. | Related data Views
Source: GO
ID: GO:0061072 |
| | |

Ontologies

| Keywords | |
|---------------------------|--|
| Biological process | Differentiation
Transcription
Transcription regulation |
| Cellular component | Nucleus |
| Coding sequence diversity | Alternative splicing |
| Disease | Disease mutation
Mental retardation
Peters anomaly |
| Domain | Homeobox
Paired box |
| Ligand | DNA-binding |
| Molecular function | Developmental protein
Repressor |
| PTM | Ubiquitination |
| Technical term | 3D-structure
Complete proteome
Reference proteome |
| Gene Ontology (GO) | |
| Biological process | astrocyte differentiation
Inferred from electronic annotation. Source: Compara
axon guidance
Inferred from electronic annotation. Source: Compara
blood vessel development
Inferred from mutant phenotype (PubMed 7550230). Source: DFLAT
cell fate determination
Inferred from electronic annotation. Source: Compara
central nervous system development
Traceable author statement (PubMed 10747901). Source: ProtInc |

Move to the bottom of your list of **GO** entries. Follow the link back to **PAX6_HUMAN**.

[View in the UniProt website: PAX6_HUMAN](#)

Move to the **Ontologies** Section. You will see confirmation of the major domains of **PAX6** and its molecular function suggested by **Keywords** and **Gene Ontology**. Stricter use of keywords must reduce the failures of annotation searches as were experienced previously.

| |
|---|
| smoothened signaling pathway |
| Inferred from electronic annotation. Source: Compara |
| visual perception |
| Traceable author statement (Ref21). Source: ProtInc |
| cytoplasm |
| Inferred from direct assay (PubMed 17291498). Source: UniProtKB |
| nuclear chromatin |
| Inferred from direct assay (PubMed 20592023). Source: BHF-UCL |
| AT DNA binding |
| Inferred from electronic annotation. Source: Compara |
| RNA polymerase II core promoter sequence-specific DNA binding |
| Inferred from direct assay (PubMed 20592023). Source: BHF-UCL |
| double-stranded DNA binding |
| Inferred from electronic annotation. Source: Compara |
| histone acetyltransferase binding |
| Inferred from sequence or structural similarity. Source: BHF-UCL |
| protein kinase binding |
| Inferred from sequence or structural similarity. Source: BHF-UCL |
| sequence-specific DNA binding RNA polymerase II transcription factor activity |
| Inferred from direct assay (PubMed 20592023). Source: BHF-UCL |
| transcription factor binding |
| Inferred from sequence or structural similarity. Source: BHF-UCL |
| ubiquitin-protein ligase activity |
| Inferred from sequence or structural similarity. Source: UniProtKB |
| Complete GO annotation... |

Following the **Keywords** are a large number of relevant **GO** terms classified as **Biological process**, **Cellular component** or **Molecular function**.

¹²² I include two examples I thought particularly pertinent. The first is a **molecular function**, the second is a **biological process**. Both were on the first page of **GO** entries.

Move to the top of the page. Here there are links to **Clusters** of proteins with sequences **100%**, **90%** and **50%** identical that of **PAX6**. These clusters, constructed from **UniprotKB**, are organised into the databases **UniRef100**, **UniRef90** and **UniRef50**. Comparing proteins with cluster databases produces more succinct results that would be generated by a search against **Uniprot** itself. Follow the links to each cluster report. Note that you can **Customize** the display. Fun, but maybe it is easier just to follow the link to the entire entry in order to obtain more information.

| Cluster ID | Status | Cluster name | Size | Cluster member(s) | Organisms | Length | Identity |
|----------------------------------|--------|-----------------------------------|------|--|---|--------|----------|
| UniRef100_P26367 | | Cluster: Paired box protein Pax-6 | 10 | P26367
P63015
Q66SS1
F2Z5M7
F6S4R0
F7C9R7
G1P774
H0XKU3
I7G9J6
D3DQZ8 | Homo sapiens (Human)
Mus musculus (Mouse)
Sus scrofa (Pig)
Callithrix jacchus (White-tufted-ear marmoset)
Macaca mulatta (Rhesus macaque)
Myotis lucifugus (Little brown bat)
Otolemur garnettii (Small-eared galago) (Garnett's greater bushbaby)
Macaca fascicularis (Crab-eating macaque) (Cynomolgus monkey) | 422 | 100% |

| Cluster ID | Status | Cluster name | Size | Cluster member(s) | Organisms | Length | Identity |
|---------------------------------|--------|-----------------------------------|------|---|--|--------|----------|
| UniRef90_P26367 | | Cluster: Paired box protein Pax-6 | 56 | P26367
P63015
Q66SS1
F2Z5M7
F6S4R0
F7C9R7
G1P774
H0XKU3
I7G9J6
+46 | Homo sapiens (Human)
Mus musculus (Mouse)
Sus scrofa (Pig)
Callithrix jacchus (White-tufted-ear marmoset)
Macaca mulatta (Rhesus macaque)
Myotis lucifugus (Little brown bat)
Otolemur garnettii (Small-eared galago) (Garnett's greater bushbaby)
Macaca fascicularis (Crab-eating macaque) (Cynomolgus monkey)
Latimeria chalumnae (West Indian ocean coelacanth)
+15 | 422 | 90% |

| Cluster ID | Status | Cluster name | Size | Cluster member(s) | Organisms | Length | Identity |
|---------------------------------|--------|-----------------------------------|------|--|---|--------|----------|
| UniRef50_P26367 | | Cluster: Paired box protein Pax-6 | 231 | P26367
P63015
Q66SS1
F2Z5M7
F6S4R0
F7C9R7
G1P774
H0XKU3
I7G9J6
+221 | Homo sapiens (Human)
Mus musculus (Mouse)
Sus scrofa (Pig)
Callithrix jacchus (White-tufted-ear marmoset)
Macaca mulatta (Rhesus macaque)
Myotis lucifugus (Little brown bat)
Otolemur garnettii (Small-eared galago) (Garnett's greater bushbaby)
Macaca fascicularis (Crab-eating macaque) (Cynomolgus monkey)
Latimeria chalumnae (West Indian ocean coelacanth)
+123 | 422 | 50% |

Move again to the **UniRef100** cluster report.

[UniRef100_P26367](#) Cluster: Paired box protein Pax-6 Follow the link to the **UniRef100** entry.

What was the **seed sequence** upon which this cluster was built? _____

What do you imagine a **seed sequence** might be (click for Help)? _____

What is the **Representative sequence** protein for this cluster? _____

What do you imagine a **Representative sequence** might be (click for Help)? _____

How many sequences are from **UniProtKB/Swiss-Prot** and how many from **UniprotKB/TrEMBL** (Look at the **Dataset** pull down Menu)? _____

Given your last answer, how would you interpret the colours of the stars in the **Status** column? _____

Select all the sequences of the **UniRef100** entry.

| |
|--|
| <input checked="" type="checkbox"/> P26367 |
| <input checked="" type="checkbox"/> P63015 |
| <input checked="" type="checkbox"/> Q66SS1 |
| <input checked="" type="checkbox"/> F2Z5M7 |
| <input checked="" type="checkbox"/> F6S4R0 |
| <input checked="" type="checkbox"/> F7C9R7 |
| <input checked="" type="checkbox"/> G1P774 |
| <input checked="" type="checkbox"/> H0XKU3 |
| <input checked="" type="checkbox"/> I7G9J6 |
| <input checked="" type="checkbox"/> D3DQZ8 |

| | | | | |
|--|---------|---------|----------|------------|
| Search | Blast * | Align * | Retrieve | ID Mapping |
| Sequences (in FASTA format) or UniProt identifiers | | | | |
| P26367
P63015
Q66SS1
F2Z5M7
F6S4R0
F7C9R7
G1P774
H0XKU3
I7G9J6
D3DQZ8 | | | | |
| | | | Align | Clear |

Click the **Align** tab at the very top of the page.

Click the **Align** button.

Try some Annotation options. Even all of them!!

| | | | | |
|----|---|-----|--------|--------------|
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | P26367 | PAX6_HUMAN |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | P63015 | PAX6_MOUSE |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | Q66SS1 | Q66SS1_HUMAN |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | F2Z5M7 | F2Z5M7_PIG |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | F6S4R0 | F6S4R0_CALJA |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | F7C9R7 | F7C9R7_MACMU |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | G1P774 | G1P774_MYOLU |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | H0XKU3 | H0XKU3_OTOGA |
| 27 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 86 | I7G9J6 | I7G9J6_MACFA |
| 61 | QKIVELAHSGARPCDISRILQVSNGCVSKILGRYYTGSIRPRAIGGSKPRVATPEVVSK | 120 | D3DQZ8 | D3DQZ8_HUMAN |

| Annotation | |
|-------------------------------------|----------------------|
| <input checked="" type="checkbox"/> | Sequence conflict |
| <input checked="" type="checkbox"/> | Natural variant |
| <input checked="" type="checkbox"/> | Beta strand |
| <input checked="" type="checkbox"/> | Turn |
| <input checked="" type="checkbox"/> | Alternative sequence |
| <input checked="" type="checkbox"/> | Compositional bias |
| <input checked="" type="checkbox"/> | Chain |
| <input checked="" type="checkbox"/> | Domain |
| <input checked="" type="checkbox"/> | DNA binding |
| <input checked="" type="checkbox"/> | Helix |

Which sequences react to the Annotation request, and why?

It is clear from the alignment that all the UniRef100 entry sequence are not, in this case at least, identical!

| | | | | | |
|---|--|--|--------|--------------|--------------|
| 1 | ----- | MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | P26367 | PAX6_HUMAN |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | P63015 | PAX6_MOUSE |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | Q66SS1 | Q66SS1_HUMAN |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | F2Z5M7 | F2Z5M7_PIG |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | F6S4R0 | F6S4R0_CALJA |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | F7C9R7 | F7C9R7_MACMU |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | G1P774 | G1P774_MYOLU |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | H0XKU3 | H0XKU3_OTOGA |
| 1 | ----- | -MQN SH SG V N Q L G G V F V N G R P L P D S T R | 26 | I7G9J6 | I7G9J6_MACFA |
| 1 | MCEAFYCESQQTSEISGNPIFEPRGIPRPPARASMQNSHSGVNQLGGVFVNGRPLPDS | 60 | D3DQZ8 | D3DQZ8_HUMAN | |

Can you rationalize why one of the sequences is allowed to be different to all the others?

After viewing this UniRef100 entry, how “non-redundant” would you say was UniprotKB?

Why do you suppose it might be useful to have identical sequences in UniprotKB?



Further Features of Ensembl

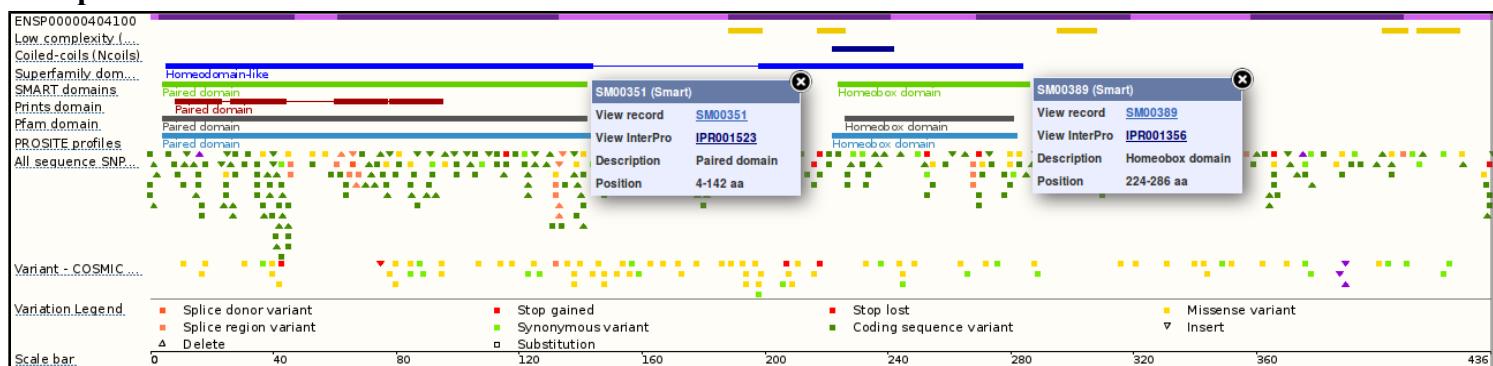
This is really some final steps I removed from the main **Ensembl** investigation in order to speed things along a trifle. Not sufficiently vital to leave in place, but still “interesting”? So I make them a supplementary exercise. I hope to add some more material covering the extended variation features of **Ensembl** later.

These instructions assume you are looking at the PAX6-201 transcript of the human PAX6 gene. If that is not where you are, the URL is:

http://www.ensembl.org/Homo_sapiens/Transcript/Summary?db=core;g=ENSG00000007372;r=11:31806340-31839509;t=ENST00000419022

Just click on the link and you should be taken to the appropriate page. Then ... proceed as follows:

Click on the **Protein Summary** link (from **Transcript-based displays** → **Protein Information**). The graphic shows the **SMART** domains you recently noted. Click on the **SMART** features. Note that feature start/end points and **Interpro** links are also available here.



Click on the **Gene: PAX6** tab. Click on the **Variation Table** link (from **Gene-based displays** → **Gene Variation**).

| Number of variant consequences | Type | Description |
|--------------------------------|------|--|
| 0 | - | Transcript ablation
A feature ablation whereby the deleted region includes a transcript feature (SO_0001893) |
| 318 | Show | Splice donor variant
A splice variant that changes the 2 base region at the 5' end of an intron (SO_0001575) |
| 374 | Show | Splice acceptor variant
A splice variant that changes the 2 base region at the 3' end of an intron (SO_0001574) |
| 114 | Show | Stop gained
A sequence variant whereby at least one base of a codon is changed, resulting in a premature stop codon, leading to a shortened transcript (SO_0001587) |
| 54 | Show | Frameshift variant
A sequence variant which causes a disruption of the translational reading frame, because the number of nucleotides inserted or deleted is not a multiple of three (SO_0001589) |
| 9 | Show | Stop lost
A sequence variant where at least one base of the terminator codon (stop) is changed, resulting in an elongated transcript (SO_0001578) |
| 0 | - | Start lost
A codon variant that changes at least one base of the canonical start codon (SO_0002012) |
| 0 | - | Transcript amplification
A feature amplification of a region containing a transcript (SO_0001899) |
| 10 | Show | Inframe insertion
An inframe non synonymous variant that inserts bases into the coding sequence (SO_0001821) |
| 0 | - | Inframe deletion
An inframe non synonymous variant that deletes bases from the coding sequence (SO_0001822) |
| 0 | - | protein altering variant
A sequence variant which is predicted to change the protein encoded in the coding sequence (SO_0001818) |
| 1016 | Show | Misense variant
A sequence variant, that changes one or more bases, resulting in a different amino acid sequence but where the length is preserved (SO_0001583) |
| 670 | Show | Splice region variant
A sequence variant in which a change has occurred within the region of the splice site, either within 1-3 bases of the exon or 3-8 bases of the intron (SO_0001630) |
| 0 | - | Incomplete terminal codon variant
A sequence variant where at least one base of the final codon of an incompletely annotated transcript is changed (SO_0001626) |
| 585 | Show | Synonymous variant
A sequence variant where there is no resulting change to the encoded amino acid (SO_0001819) |
| 0 | - | Stop retained variant
A sequence variant where at least one base in the terminator codon is changed, but the terminator remains (SO_0001567) |
| 2740 | Show | Coding sequence variant
A sequence variant that changes the coding sequence (SO_0001580) |
| 0 | - | Mature miRNA variant
A transcript variant located with the sequence of the mature miRNA (SO_0001620) |
| 200 | Show | 5 prime UTR variant
A UTR variant of the 5' UTR (SO_0001623) |
| 375 | Show | 3 prime UTR variant
A UTR variant of the 3' UTR (SO_0001624) |
| 3358 | Show | Non coding transcript exon variant
A sequence variant that changes non-coding exon sequence in a non-coding transcript (SO_0001792) |
| 15257 | Show | Intron variant
A transcript variant occurring within an intron (SO_0001627) (WARNING: table may not load for this number of variants!) View list in BioMart |
| 0 | - | NMD transcript variant
A variant in a transcript that is the target of NMD (SO_0001621) |
| 8409 | Show | Non coding transcript variant
A transcript variant of a non coding RNA gene (SO_0001619) (WARNING: table may not load for this number of variants!) View list in BioMart |
| 6631 | Show | Upstream gene variant
A sequence variant located 5' of a gene (SO_0001631) (WARNING: table may not load for this number of variants!) View list in BioMart |
| 7114 | Show | Downstream gene variant
A sequence variant located 3' of a gene (SO_0001632) (WARNING: table may not load for this number of variants!) View list in BioMart |
| 38149 | Show | ALL
All variations (WARNING: table may not load for this number of variants!) View list in BioMart |

You are rewarded by a table offering to show various subsets (or ALL) of the **Variations** coincident with the **PAX6** region of the human genome. In the next section of the exercise, you will also generate a list of SNPs for **PAX6**, but this option allows for much greater refinement. Click on some of the **Show** options offered. I would imagine the **Splice donor variants** and **Splice acceptor variants** that occur in the critical start and end base pairs of introns would be of particular interest in “Real Life”.

You will see from the lists you produce, many of these mutations are from the HGMD and reveal little, unless you pay. There are more useful entries elsewhere however. Have a look around. For my illustration, starting with the list of all **Splice acceptor variants**, I removed some of the table columns that did not contain obviously interesting information using the [Show/hide columns](#) option at the top of the table.

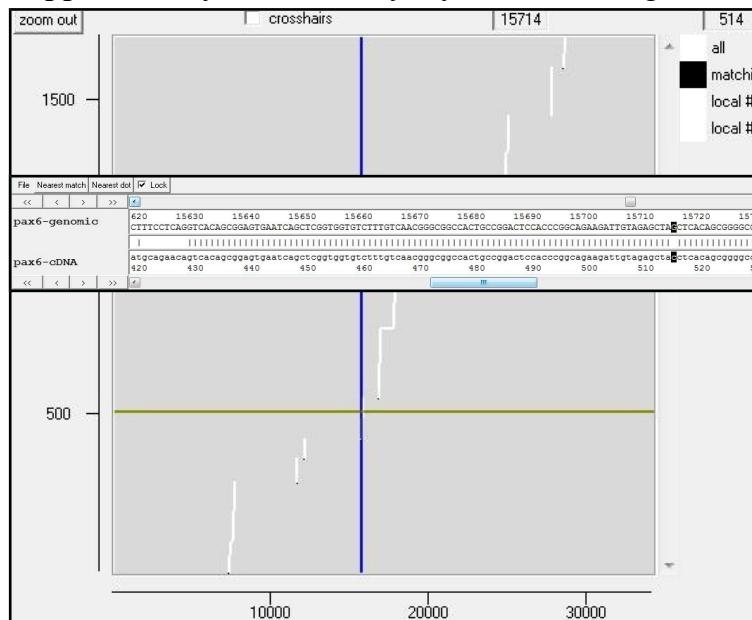
| | | | | | | |
|-----------------------------|-------------|---------------|---------------------|-------------|---|---------------------------------|
| COSM4032358 | 11:31790861 | C/T | somatic_SNV | COSMIC | Splice acceptor variant
 Non coding transcript variant | ENST00000494377 |
| COSM926339 | 11:31790861 | C/A | somatic_SNV | COSMIC | Splice acceptor variant
 Non coding transcript variant | ENST00000494377 |
| COSM4032358 | 11:31790861 | C/T | somatic_SNV | COSMIC | Splice acceptor variant
 Non coding transcript variant | ENST00000533333 |
| COSM926339 | 11:31790861 | C/A | somatic_SNV | COSMIC | Splice acceptor variant
 Non coding transcript variant | ENST00000533333 |
| COSM4032358 | 11:31790861 | C/T | somatic_SNV | COSMIC | Splice acceptor variant | ENST00000606377 |
| COSM926339 | 11:31790861 | C/A | somatic_SNV | COSMIC | Splice acceptor variant | ENST00000606377 |
| CS068282 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000241001 |
| CS982311 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000241001 |
| CS068282 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379107 |
| CS982311 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379107 |
| CS068282 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379109 |
| CS982311 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379109 |
| CS068282 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379111 |
| CS982311 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379111 |
| CS068282 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379115 |
| CS982311 | 11:31793554 | HGMD_MUTATION | sequence_alteration | HGMD-PUBLIC | Splice acceptor variant | ENST00000379115 |

Try the **Variation Image** link. This offers the same information, dressed up as an enormous graphic! Indubitably pulchritudinous, but the poetry is a tad over blown for a simple lad such as I.



Further Features of Spin

This **Supplementary Exercise** assumes you to be exactly as you would be if you had just finished the main pairwise alignment exercise with **spin**, ending with a look at **Local Alignment**. I moved it here to try and make things a little shorter. It really only shows a few extra features of **spin** whilst, obsessively, trying to get **spin** to translate the unaffected sequence to show explicitly that the amino acid that is mutated into a **Proline** is an **Alanine**. I only partially and clumsily succeeded with the latter and you knew the answer anyway! So it only just deserves to be a **Supplementary Exercise**. Anyway, for what it might be worth, here it is.



The fact that your alignments are not in positional order does make it a little difficult to find things. In particular, the mutation in the coding exon. **splign** suggests this is in the 5th exon. One way to view it therefore would be to

double click on the 5th exon of the graphical display.

This will bring the

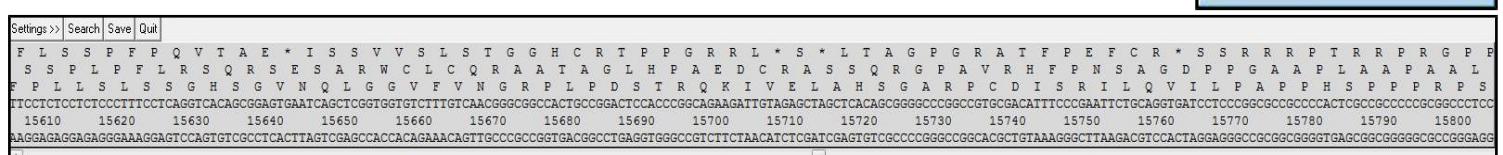
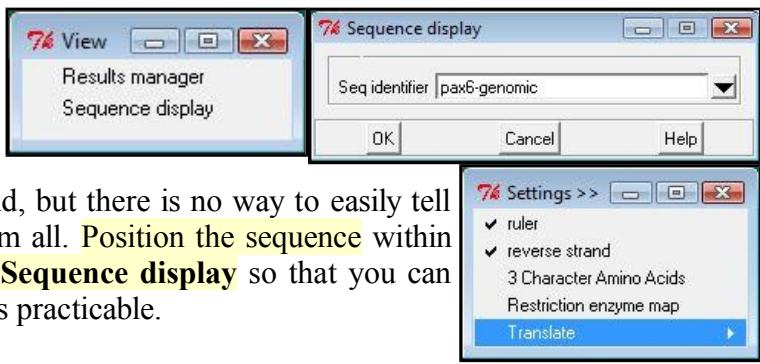
Sequence Comparison Display into view. Click on the **Nearest match** button to view the alignment for the 5th exon. Click on the **Lock** button so that the cDNA and genomic sequences stay in alignment. Make the **Sequence Comparison Display** as wide as you can. Move the display along until you have the mutation in view. Wonderful, but we have not persuaded any of the software to declare what the translation of the wild type sequence would be at the mutation site¹²³.

From **spin's View menu**, select **Sequence display**.

Check that the genomic sequence is selected. Click **OK**.

You should now be viewing the genomic sequence. To add amino acid translations, from the **Settings menu**, select **Translate** and choose to **Translate + frames**. You

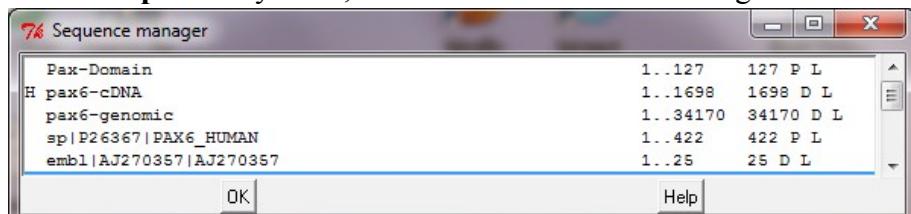
know the coding reading frame must be on the top strand, but there is no way to easily tell which of the three frames it might be¹²⁴, so translate them all. Position the sequence within your display so that the mutation is in view. Shape the **Sequence display** so that you can easily see all three translations and as much sequence as is practicable.



Maybe using your **splign** results to help you decide, which reading frame is coding in the 5th exon?

What is the amino acid corresponding to the mutated base in the PAX6 genomic sequence?

At this point, the unworthy cynic might note that we have known all this from the time we looked at the feature table of the **Uniprot** entry. True, but how much more rewarding to have worked it all out for ourselves!



Time to tidy up. Remove as many of your textual outputs from **spin's Output window** as your patience allows. You have saved all that might be useful later. Dispose of **spin's** graphics windows and **Sequence displays**, all were very beautiful in their time but have

now served their purpose fully. In the next section, you will be analysing the mRNA (**pax6-cDNA**), so set it as **spin's** **Horizontal sequence** in the **Sequence manager**. From this point on, you will be using a lot of **EMBOSS** programs from **spin**. All **EMBOSS** programs are selected from **spin's Emboss menu**, even if I do not explicitly state this each and every time.

123 Yes I know we could work it out using the table in the appendix ... but that would be like “reading the manual”!! Exclusively for wimps!

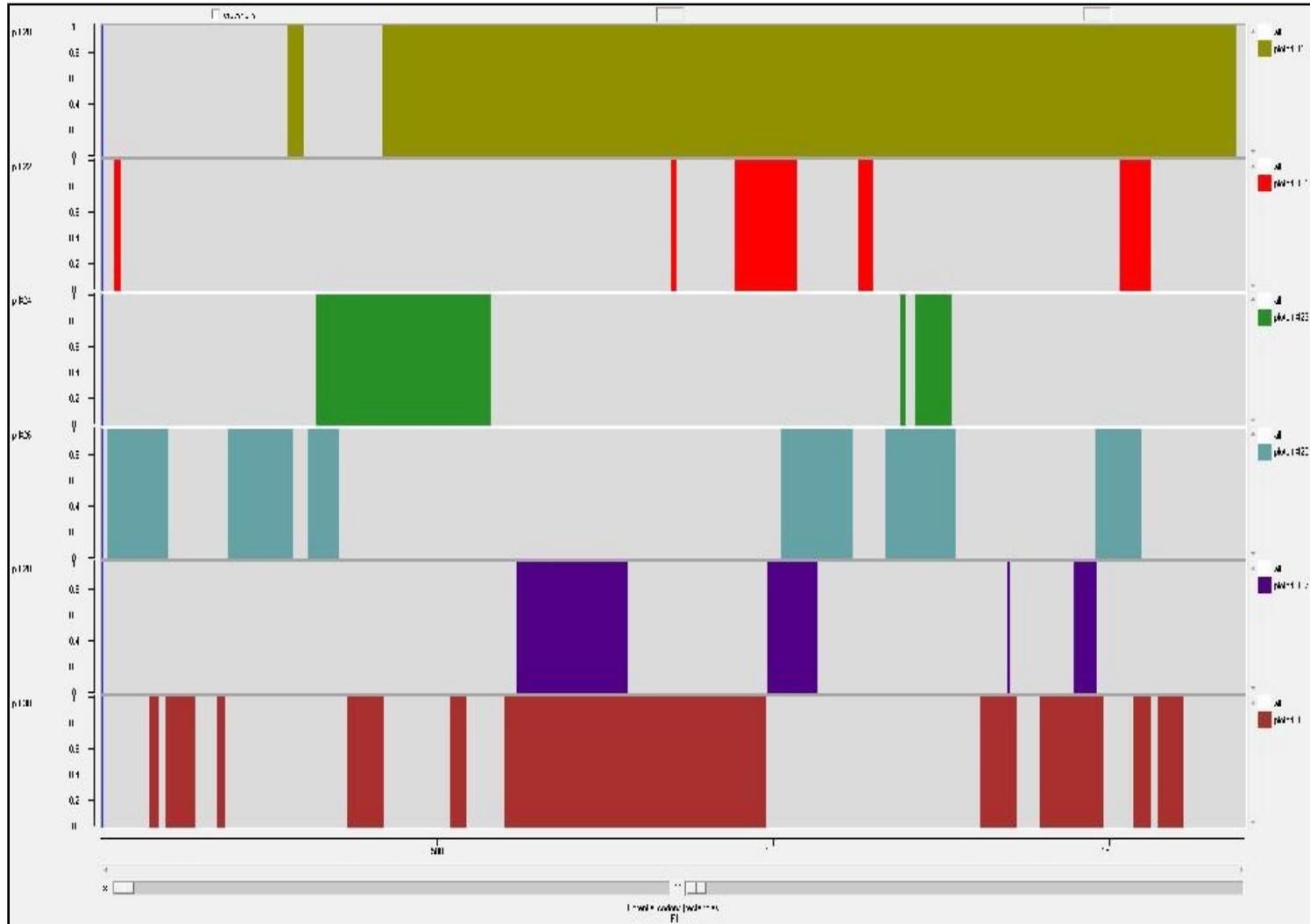
124 Well, OK there is .. but let us be lazy.



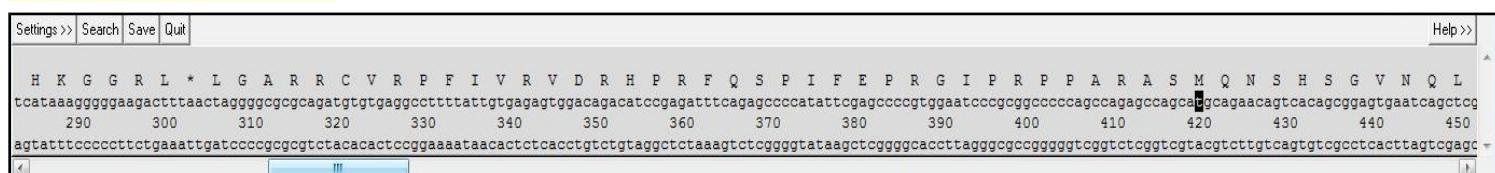
ORF Identification and Translation

Now identify and translate the coding portion of the cDNA sequence into protein. The **EMBOSS** program **plotorf** provides a preliminary graphic of the distribution of ORFs in six frames.

From **spin's Emboss** menu, select **plotorf** from the **Nucleic/Gene Finding** menu. Use the default start/stop codons (**Advanced section**). Click **OK**.



You will see a graphical output that shows the potential open reading frames (ORF) in all six-frames. You will notice that the longest ORF occurs in the top section of the graphic (*i.e.* forward sense, frame 1) starting at around **400** bases and ending around **1700**. Try using the cross-hair to obtain a more accurate estimate of the start of the longest ORF. Double click in the graphic, **spin** will produce a sequence display in which you can request a translation of the appropriate reading frame. From this display, it is easy to determine the extent of the ORF and the coding region¹²⁵.



You have passed over several opportunities to record the exact start and stop positions of the coding region of your cDNA. Maybe this is the moment to make a note. You need to know that in the **spin Sequence Display** the numbered base is below the least significant digit. Thus both the **340th** base and the **380th** base are As. Also, the last Stop (*) before the coding region of this mRNA spans bases **301** to **303**.

At what base position does the coding sequence of the mRNA commence? _____

Move the **Sequence Display** along to the region in which **plotorf** suggests the coding sequence ends.

What is the base position of the last base of the coding sequence? _____

¹²⁵ The crosshair and the sequence display are both **Staden** features that have been made to work for many of the **EMBOSS** programs.

Other ways to determine the whereabouts of coding regions include use of the **EMBOSS** program **getorf**¹²⁶. Select **getorf** from the **Nucleic/Gene finding** menu. In the **Additional section**, ensure that the **Code to use** is set to **Standard**. Use your **plotorf** results to select a sensible **Minimum nucleotide size of ORF to report**¹²⁷. Select **Translation of regions between START and STOP codons** for the **Type of output**. In the **Output section**, change the **Filename** to **getorf_results.txt** and hit **OK**.

Look at your **getorf** results file with an editor. The number of “answers” **getorf** suggests will depend upon the minimum **ORF** size you chose. **plotorf** suggests that the correct (most likely at least) **ORF** will be in the region **400** to **1700**. Find the relevant prediction in your **Sequence Display** output. You will (again) see that the translation is from **418** to **1683**.

In **spin's Sequence Manager**, ensure **pax6_cDNA** is the **Horizontal sequence**¹²⁸.

To save the translation of this region, pick the **EMBOSS** program **transeq**¹²⁹ from the **Nucleic/Translation** menu. Move to the **Additional section**, and set the **Regions to translate** to **418-1683**. Ensure **Translation Frames** is set to **1**, and **Code to use** to **Standard**. In the **Output section** set the **Filename** field to **pax6.pep**. Hit **OK**.

Using an appropriate editor, alter the comment line in your **pax6.pep** file to read “**pax6 conceptual translation from mutant cDNA**” and save you handiwork for perpetuity. Your file should appear similar to that illustrated.

```
>pax6 conceptual translation from mutant cDNA
MQNSHSGVNQLGGVFVNGRPLPDSTRQKIVELPHSGARPCDISRILQVSNGCVSKILGRY
YETGSIRPRAIGGSKPRVATPEVVSKIAQYKRECPEIFAWEIRDRLLSEGVCNTNDNIPSV
SSINRVLRNLASEKQQMGADGMYDKLRLMLNGQTGSWGTRPGWYPGTSVPQPTQDGCQQQ
EGGGENTNSISSNGEDSDEAQMRLQLKRKLQRNRTSFTQEQUIEALEKEFERTHYPDVFAR
ERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVDQPIP
QPTTPVSSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPPVPSQTSSYSCMLPT
SPSVNGRSYDTYTPPHMQTHMNSQPMGTSGTTSTGLISPVGVSVPQVPGSEPDMSQYWPR
LQ
```

Now, you are able to compare the protein sequence from your cDNA with the **PAX6** database entry. This requires a sequence alignment to make apparent any discrepancies between sequences.

Align your translated **pax6.pep** sequence with the database entry. Choose the **spin** alignment option you consider most logical (global or local, both will work, but one makes more sense than the other). Load in the protein sequence you saved in the file **pax6.pep**¹³⁰ and the **PAX6** human protein from the **Uniprot** sequence database (you will recall that you saved this in a disk file called **pax6_human.fasta** in your working directory¹³¹). The default settings should do, just set the program going and view the results.

What is the single amino acid difference between the two sequences?

What is the position of the difference?

126 Using **getorf**, as we do here, is ponderous compared with just reading along the **Sequence Display** of **spin**. However, unlike any native aspect of **spin**, **getorf** can be run without any graphics. It can be run many times from a simple script without user intervention. If you had to detect coding regions in many sequences, rather than just one, **getorf** (plus a simple script) would be the sane option.

127 You want to eliminate all the very small ORFs but not the one you consider might be the genuinely coding region (i.e. the biggest one). In “real life” one might select a rather large value to select only the longest ORF. For the exercise, maybe a smaller value to see the longest few regions would be appropriate? How about 150?

128 **spin** has an irritating tendency to assume you wish to analyse the output of the last option you executed.

129 This program may not be strictly necessary if you have already obtained the correct protein by using **getorf**.

130 You will need to use the **Load Sequence/Simple** option of the **spin File** pull down menu as it is not yet in the **Sequence manager**.

131 It should be in the Sequence manager as **sw|P226367|PAX6_HUMAN**, or you could load it directly from the **Uniprot** database at the **EBI** using the **SRS** capabilities built into **EMBOSS/spin**.

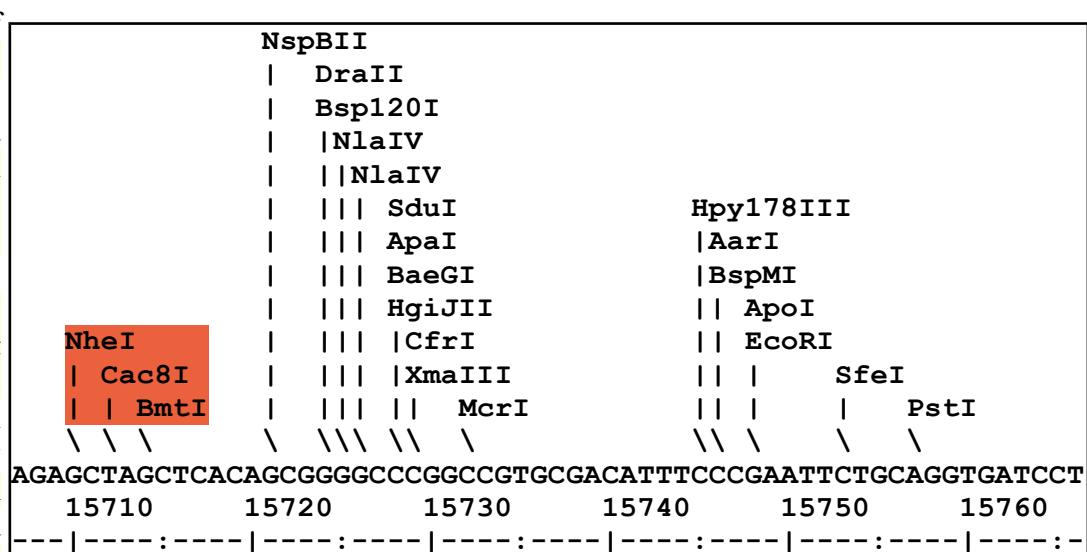
Restriction Maps

Particularly when looking at the NCBI program **splign**, you recorded the position and type of all the differences between your aniridia patient's mRNA and the genomic sequence from **Ensembl**. The most interesting mismatch is between base position **514** of the mRNA (C) and **15714** of the genomic sequence (G). You could check these positions by looking at your second global alignment (saved in **global_results02.txt**) and/or your second local alignment (saved in **local_results02.txt**), or you could just believe!

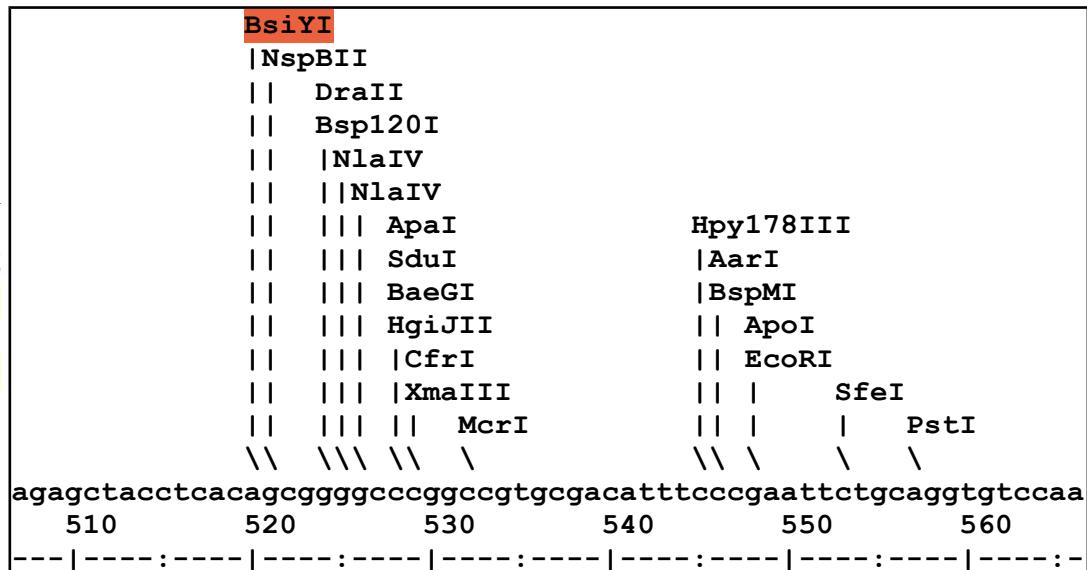
Restriction mapping is trivial using computers. Use the **EMBOSS** program **remap** to make a restriction map of each sequence in the area where the difference is seen in the alignment. Any differences in the two restriction maps could be used to further investigating the discrepancy between the two sequences¹³².

First map the relevant region of the genomic sequence. Choose **remap** from the **Nucleic/Restriction** menu and load the genomic DNA sequence. Set the **Start position** and **End position** fields to **15707** and **15766**. In the **Required section**, leave the **Comma separated enzyme list** as **all** but set the **Minimum recognition site length** to **6**. In the **Output section**, you know the translation and sense, so turn off **Display translation** and **Display cut sites and translation of reverse sense**¹³³. Set the **Output filename** to **remap_genomic.txt**. Leave all else and click on **OK**.

Your output should begin as illustrated.



Run **remap** again in the fashion outlined above for the corresponding part of the **PAX6** mutated cDNA. The region to map is from **507** to **566**. This time, set the **Output filename** to **remap_cdna.txt**.



The one base pair difference has altered the way a number of restriction enzymes cut. Differences include the deletion of the **3** restriction sites of the genomic map and the creation of the **1** site in the cDNA map. Complete information about these restriction enzymes, can be found at the **REBASE** (a publicly available database of restriction enzyme data) web site.

¹³² If there is a single restriction enzyme that cuts differently due to the mutation, it might be possible to design a **Restriction Fragment Length Polymorphism (RFLP)** test to detect the mutation in individuals. Not a likely choice these days. **PCR** would generally be regarded as a much better option. Treat **RFLP** as an excuse for doing some restriction maps if you wish.

¹³³ **BUG!!** I fear there is a bug here. These 2 options are turned **ON** even though they appear to be turned **OFF**. To really turn them **OFF**, you need to turn them **ON** and then turn them **OFF** again!! Sorry, I will try to get this fixed.

The REBASE homepage features a search bar at the top with fields for "Choose search category and enter keyword:" (using percent sign as wildcard and quotes around phrases), "author starting with", "Go", "Clear", "Go directly to enzyme:", "Go", "Clear", and "Partial enzyme name search:", "Go", "Clear". Below the search bar are links for "REBASE sequence data", "REBASE Lists", "REBASE NEWS", "REBASE Enzymes", "REBASE Suppliers", and "REBASE Methylation Sensitivity". On the left, there are links for "Submit Data to REBASE", "REBASE FILES", "HELP?", "REBASE Related Sites", "Subscribe to REBASE", "REBASE Services", and "REBASE References".

Before moving on, take a quick look around the home of REBASE. Make a new navigator window and go to:

<http://rebase.neb.com/>

You could download the REBASE in a large number of different formats (including that required by the EMBOSS package). To examine the possibilities, click on the REBASE FILES link.

- Theoretical digests with all REBASE prototypes...
- Blast your sequence against REBASE...
- New England Biolabs NEBCutter...
- REBpredictor...

For a really pretty and interactive map, starting from the REBASE home page once more, click on the REBASE Tools link.

The NEBCutter interface allows you to upload a local sequence file (pax6_genomic.fasta), browse GenBank, or paste DNA sequence in plain or FASTA format. It includes standard sequence selection for plasmid vectors or viral/phage. Options for linear or circular sequences and specific enzymes are provided, along with a minimum ORF length (100 a.a.) and a note about cookie usage. Projects can be managed via "Earlier projects" and "Delete projects".

Select New England Biolabs NEBCutter. Load sequence file **pax6_genomic.fasta** and ask for More options.

The "More options" dialog includes checkboxes for Type I & III enzymes, Homing endonucleases, Nicking enzymes, and various CpG/Dam/Dcm methylation ignore options. It also allows selecting a genetic code (Standard) and indicates if the sequence is a fragment. A "Process this region only" field specifies a range from 15707 to 15766 bp.

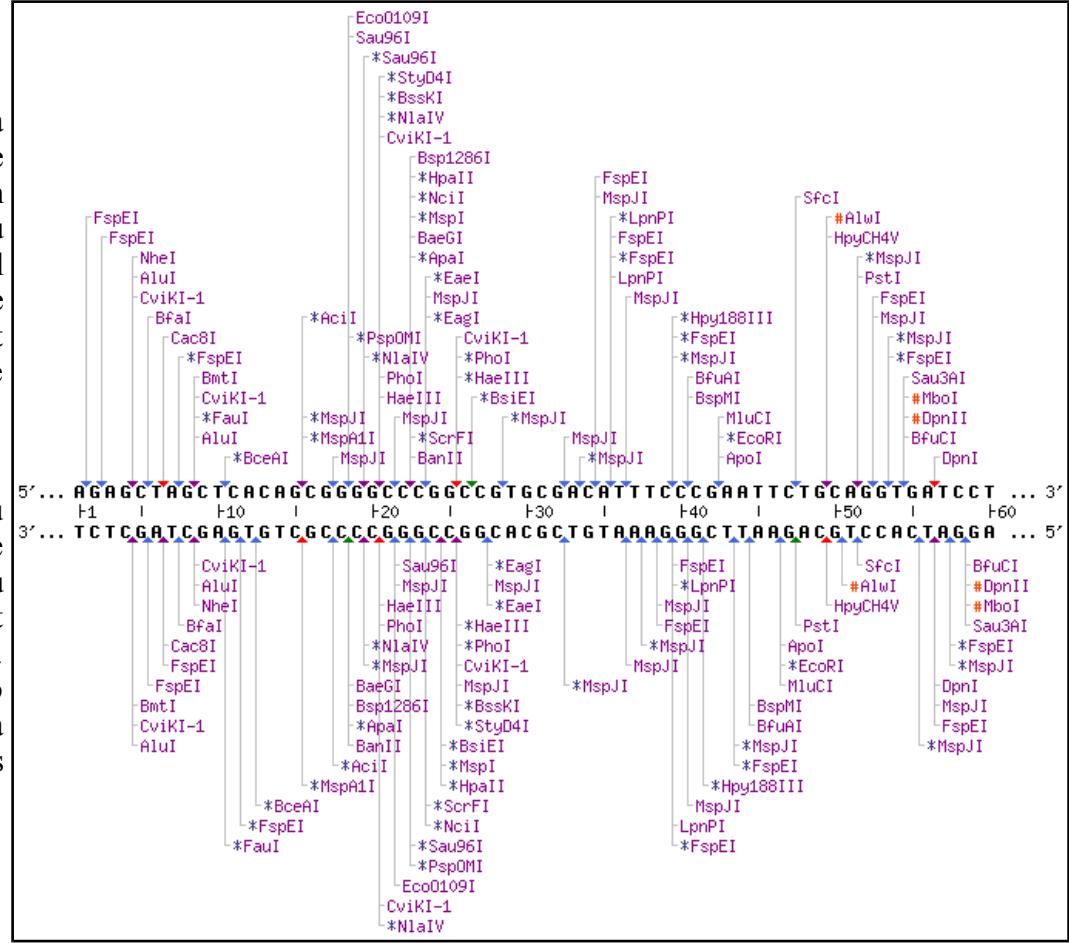
Set the Genetic code to Standard.

Elect to Process this region only from 15707 – 15766. Click OK in the More options window.

Click on Submit in the main NEBCutter window.

You will be rewarded by a beautiful map of the same genomic **PAX6** region investigated with **remap**. You can link to the individual REBASE entries and customize the map in many ways. This must be a better way to ponder the map of a specific sequence.

In order to make the map you generated look a little more like the one produced by **remap**, you would need at least to restrict the number of enzymes mapped. If you recall, you told **remap** to consider only enzymes with a recognition site of **6** base pairs or more.



Click on **Custom digest** (amongst **Main options**). You will see your map in tabular form. Click on **Enzymes with a particular site length**, choose **6 bp site** and click **OK**. Your table of enzymes will shrink dramatically to meet your specification.

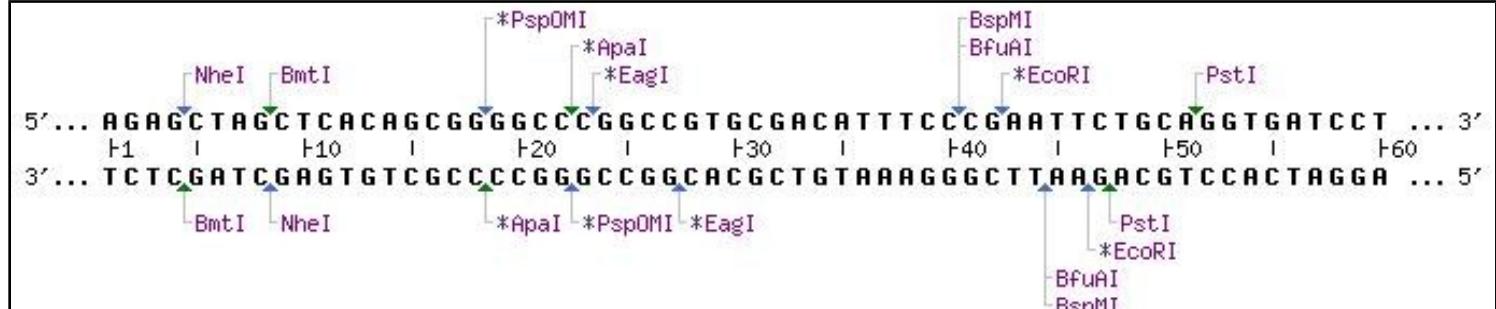
Pick all the listed enzymes and then click on the green **Digest** button at the bottom of the page to create a graphical map roughly equivalent of the one you made with **remap**.

Note that to find out about an enzyme you can hover over its name, or click on the name for fuller information. There is much more to investigate at this site. I leave you to discover for yourselves.

[3 bp site] - [4 bp site] - [4.5 bp site] - [5 bp site] - [6 bp site]

Site length between 6 and 6 OK

| Pick all | Enzyme | Specificity | Cuts | % activity in 1 | % activity in 2 | % activity in 3 | % activity in 4 |
|-------------------------------------|--------|---------------------|------|-----------------|-----------------|-----------------|-----------------|
| <input checked="" type="checkbox"/> | ApaI | G _{GGCC} C | 1 | 25 | 50 | 0 | 100 |
| <input checked="" type="checkbox"/> | BfuAI | ACCTGCNNNNNNNN | 1 | 0 | 75 | 100 | 10 |
| <input checked="" type="checkbox"/> | BmtI | G _{CTAG} C | 1 | 25 | 100 | 25 | 50 |
| <input checked="" type="checkbox"/> | BspMI | ACCTGCNNNNNNNN | 1 | ? | ? | 100 | ? |
| <input checked="" type="checkbox"/> | EagI | C _{GGCC} G | 1 | 10 | 25 | 100 | 10 |
| <input checked="" type="checkbox"/> | EcoRI | G _{AATT} C | 1 | 100 | 100 | 100 | 100 |
| <input checked="" type="checkbox"/> | NheI | G _{CTAG} C | 1 | 100 | 100 | 10 | 100 |
| <input checked="" type="checkbox"/> | PspOMI | G _{GGCC} C | 1 | 25 | 25 | 10 | 100 |
| <input checked="" type="checkbox"/> | PstI | C _{TGCA} G | 1 | 75 | 75 | 100 | 50 |



There are quite a few less enzymes mentioned in the map you have just made compared to that generated by **remap**. Can you speculate what the main reason for this might be?

Some enzymes in this map appear in the same place as **remap** predicted, but have different names. Can you explain why?



Gene Identification Software – Specifically Genscan

These programs are used to find promoters, splice sites, coding versus non-coding regions and polyadenylation signals in novel DNA sequences. These features can be combined to form complete gene model predictions.

When looking for splice sites in genomic DNA, some programs use the best currently accepted consensus (e.g. AG dinucleotide at intron/exon boundary) to scan the unknown sequence. Other programs are trained with a set of splice sites in known sequences (neural network approach). These applications often over predict. Prediction accuracy ranges between 50% and 95%. Recent programs for gene identification use Hidden Markov Models. There are many GeneID programs. One of the best single programs for *de novo* gene prediction is **Genscan**.

Genscan can recognise more than one potential gene in a sequence. It can also recognise partial genes. **Genscan** has been primarily designed for vertebrates. It may be less accurate for other organisms.

Go to the **Genscan** server at:

<http://genes.mit.edu/GENSCAN.html>

Use the default **Organism** and **Suboptimal exon cutoff**. Set **Print options** to **Predicted CDS and peptides**. Copy and paste, **just the PAX6 genomic sequence** from **pax6_genomic.fasta** into the appropriate text box. **Genscan** does not understand FASTA format. Were you to use the **Upload your DNA sequence file** option, or to copy and paste the whole of this file, **18** of the **22** characters of the first line “>pax6-genomic sequence” would be regarded as part of the sequence¹³⁴, rendering the **Genscan** output impossible to interpret.

Click on **Run GENSCAN**.

In the results that are generated, predicted genes and sub-features such as exons are numbered (**Gn.Ex**) and listed in a table displaying their **Type**, strand (**S**), start (**Begin**) and end (**End**) positions, and length (**Len**). A probability (**P**) is assigned to each predicted exon. High probability exons (**P > 0.99**) are nearly always correct, those with **0.50 < P < 0.99** are correct most of the time, the rest are not reliable.

The screenshot shows the Genscan web interface. At the top, there are dropdown menus for 'Organism' (set to 'Vertebrate') and 'Suboptimal exon cutoff (optional)' (set to '1.00'). Below these are fields for 'Sequence name (optional)' and 'Print options' (set to 'Predicted CDS and peptides'). Underneath is a large text area containing the DNA sequence. At the bottom are two buttons: 'Run GENSCAN' and 'Clear Input'.

```

Organism: Vertebrate Suboptimal exon cutoff (optional): 1.00
Sequence name (optional):
Print options: Predicted CDS and peptides
Upload your DNA sequence file (upper or lower case, spaces/numbers ignored): [input field]
Or paste your DNA sequence here (upper or lower case, spaces/numbers ignored):
ATGCGGAAGATCTGTCTTGAATTAAAAGAAATGAAAAAAACCCGGACATTC
TAAAAAAATAAGATAAGAAACCTGATTTTAGTACTAATGAAATAGCGGTGACAAAAATA
GTGTCCTTTGATTGATCACAAAAATAAACCTGGTAGTGACAGGATGATGGAGAG
ATTGACATCCTGGCAATCACTGTCAATTGATCAATTCTAATCTGAATAAAAGCT
GTATACAGTAGTTGTTATGCTACAGTGGGTTTTAAGTGACTGACATTCATCATATT
GGTTAGACAGCTTAAACCTGACTGTTCTACATGTTGCAAGAACAAATAAA
GTATAATTGTTGATATAAAGCAAGCTGCTAAAGCTAGTTAACTGCTCAA
ATATTAATACATTGAAATGTTGGAAATTCTAGTTCTCCAATGGATGTTAAA
CACCTTTAAAAATCAAGACTCTAAATATGCAAGTCTTTCACTTCAATTTTA
TCCTATTATGCTCAAAGCTTGGAAATGATGAAATTTAAACCTAATGTTCA
TATGAAAATGCTTGGATATGCTTACATCCCCCAAAGACATGTTACATGTTAGAAATT
ACACACTCAACCAATGTTCAATTAAACAAATATTATGATGCAATGGAATCTGAG
TTAGTTTCACTTTCTCACTTGTCTCAGAC
Run GENSCAN Clear Input

```

| Gn.Ex | Type | S | .Begin | ...End | .Len | Fr | Ph | I/Ac | Do/T | CodRg | P.... | Tscr.. | S.Start | S.Fin |
|-------|------|---|--------|--------|------|----|----|------|------|-------|-------|--------|---------|-------|
| 1.01 | Init | + | 5509 | 5600 | 92 | 0 | 2 | 65 | 24 | 139 | 0.462 | 3.17 | 7245 | 7347 |
| 1.02 | Intr | + | 7682 | 8297 | 616 | 2 | 1 | 37 | 65 | 397 | 0.257 | 24.65 | 7447 | 7634 |
| 1.03 | Intr | + | 12000 | 12060 | 61 | 2 | 1 | 96 | 98 | 38 | 0.917 | 3.91 | 11537 | 11613 |
| 1.04 | Intr | + | 12789 | 13073 | 285 | 1 | 0 | 92 | 107 | 50 | 0.900 | 4.61 | 12000 | 12060 |
| 1.05 | Intr | + | 15326 | 15442 | 117 | 0 | 0 | 71 | 52 | 55 | 0.567 | 0.64 | 15628 | 15758 |
| 1.06 | Intr | + | 15628 | 15758 | 131 | 2 | 2 | 141 | 58 | 149 | 0.999 | 17.61 | 16686 | 16901 |
| 1.07 | Intr | + | 16550 | 16591 | 42 | 1 | 0 | 62 | 85 | 51 | 0.608 | 0.64 | 17606 | 17771 |
| 1.08 | Intr | + | 16686 | 16901 | 216 | 2 | 0 | 104 | 94 | 112 | 0.995 | 12.10 | 23674 | 23832 |
| 1.09 | Intr | + | 17606 | 17771 | 166 | 1 | 1 | 76 | 93 | 72 | 0.974 | 6.03 | 24348 | 24430 |
| 1.10 | Intr | + | 17856 | 17927 | 72 | 1 | 0 | 88 | 42 | 58 | 0.553 | 0.58 | 24660 | 24810 |
| 1.11 | Intr | + | 23674 | 23832 | 159 | 2 | 0 | 108 | 54 | 194 | 0.919 | 17.96 | 24909 | 25024 |
| 1.12 | Intr | + | 24348 | 24430 | 83 | 1 | 2 | 29 | 86 | 85 | 0.945 | 1.76 | 27602 | 27752 |
| 1.13 | Intr | + | 24660 | 24810 | 151 | 2 | 1 | 72 | 58 | 76 | 0.958 | 2.74 | 28443 | 28540 |
| 1.14 | Intr | + | 24909 | 25024 | 116 | 1 | 2 | 113 | 108 | 94 | 0.977 | 14.07 | | |
| 1.15 | Intr | + | 27602 | 27752 | 151 | 1 | 1 | 115 | 99 | 80 | 0.992 | 11.54 | | |

Illustrated here are the results I got alongside the very authoritative predictions from **splign** that you computed from the same data earlier. Overall, the prediction is more than reasonable, given the approximate nature of the training set. Observations include:

- 9 of the 10 genes suggested by **splign** between bases 12000 and 28540 were predicted exactly by **Genscan**.

¹³⁴ The “>”, “-”, “6” and the space would be thrown away. Many, but not all, of the other 18 characters are valid DNA ambiguity codes (see Appendix I). GENSCAN seems willing to attach meaning to *all* the letters, even the ones not part of the IUB alphabet?

- Genscan missed the final exon (**28443-2850**) and so failed to predict a complete gene.
- Of the 4 exons Genscan predicts in this region but **spliced** denies, one is the **42** base pair exon that is only present in **isoform 5a**. This is genuine, but **spliced** would not see it as the cDNA used was not an **isoform 5a** sequence.
- The other 3 “extra” exons in this region were all predicted with suspiciously low probability scores (**17856-17927 P=0.553, 16550-16591 P=0.608, 15326-15442 P=0.567**).
- Genscan has not made a particularly impressive job of predicting the non-coding exons at the **5'** end of the gene.

Explanation

```

Gn.Ex : gene number, exon number (for reference)
Type   : Init = Initial exon (ATG to 5' splice site)
           Intr = Internal exon (3' splice site to 5' splice site)
           Term = Terminal exon (3' splice site to stop codon)
           Sngl = Single-exon gene (ATG to stop)
           Prom = Promoter (TATA box / initiation site)
           FlyA = poly-A signal (consensus: AATAAA)
S      : DNA strand (+ = input strand; - = opposite strand)
Begin  : beginning of exon or signal (numbered on input strand)
End    : end point of exon or signal (numbered on input strand)
Len    : length of exon or signal (bp)
Fr     : reading frame (a forward strand codon ending at x has frame x mod 3)
Ph     : net phase of exon (exon length modulo 3)
I/Ac   : initiation signal or 3' splice site score (tenth bit units)
Do/T   : 5' splice site or termination signal score (tenth bit units)
CodRg  : coding region score (tenth bit units)
P      : probability of exon (sum over all parses containing exon)
Tscr   : exon score (depends on length, I/Ac, Do/T and CodRg scores)

```

A full explanation of the output table used to be included at the bottom of the results page. It has now been removed, but as I think it was useful, I include it here. Note that **Intr** is not short for **Intron**, as most sensible people might guess, it is short for **Internal exon!!** I suspect a warped sense of humour here?

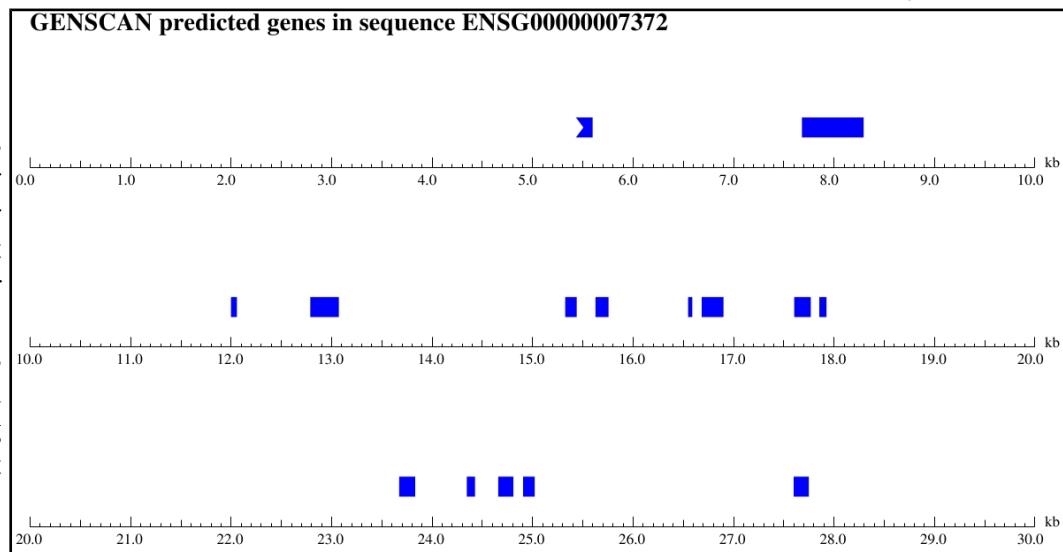
Another way to gain an impression of how well Genscan has performed, is to align the predicted protein with the protein from UniProtKB that you have stored in **pax6_human.fasta**. To save time, I have done that for you with the **EMBOSS** program **needle** (sensitive global alignment option). **needle** was run with default parameters from the **EBI** web pages. I have edited the output in this illustration, but only to reduce its size.

Genscan has regarded all the exons it predicts as coding, hence the messy beginning. The effects of the missing internal exons are very clear to see, including the familiar **14** amino acids of **isoform 5a**, missing in the **UniprotKB** entry, but correctly predicted by Genscan.

The consequences of the missing terminating exon is also clear to see.

| | | | |
|--------------|-----|---|-----|
| GENS CAN pep | 1 | MWP GGP GLAASSLSRLPGAAATRPVSSERQVSPFLPPSFLPSRSPPP | 50 |
| GENS CAN pep | 51 | LLRRESWAGEVSTQEPKLSLSTSSESPRRRATAGERRRRARGGRPAQPQRQ | 100 |
| GENS CAN pep | 101 | RQRQRGLSSREEGRLQARQQPQLLAPASPNAPDPREKTKRLCGAQGPGTA | 150 |
| GENS CAN pep | 151 | AESNRCCRLLCPARGPANAQRAGAPTRRRGSAETCSSPRLRPPAGPRALCR | 200 |
| GENS CAN pep | 201 | TGLRRRRVSRHSSAEGGTAPATSPSGVSRQGSRTLESPIFEPRGIPRPPA | 250 |
| GENS CAN pep | 251 | RASMQNNPVGSHPPSCSWWVLVRGRASLELRPGSLEAQRNQARFEVTVEA | 300 |
| GENS CAN pep | 301 | HGVGAQLN SKCGKARVFQQPALAEPHRLKEGPQHLIHLHFWKRRSPGAGS | 350 |
| GENS CAN pep | 351 | AVQWAGARLLGLGCPMSGMAGGPVVLYLIDSRELTAEVG TGHS GVQNQLGG | 400 |
| | | | |
| PAX6_HUMAN | 1 | MONSHSGVNQLGG | 13 |
| GENS CAN pep | 401 | VFVN GRPLPDSTRQKIVELAHS GARPC DISRILQ THADAKVQVLDNQNV | 450 |
| | | | |
| PAX6_HUMAN | 14 | VFVN GRPLPDSTRQKIVELAHS GARPC DISRILQ-----VS | 49 |
| GENS CAN pep | 451 | NGCV SKILG RYYETGSIRP RAIGGS KSPR VATPEV VSKIA QYKRCPSIFA | 500 |
| | | | |
| PAX6_HUMAN | 50 | NGCV SKILG RYYETGSIRP RAIGGS KSPR VATPEV VSKIA QYKRCPSIFA | 99 |
| GENS CAN pep | 501 | WEIRD RLSEG VCTND NIPS VSSIN RVRLN LASEK QOMGAD GMYDKL RML | 550 |
| | | | |
| PAX6_HUMAN | 100 | WEIRD RLSEG VCTND NIPS VSSIN RVRLN LASEK QOMGAD GMYDKL RML | 149 |
| GENS CAN pep | 551 | NGQT GS WGT RGP GWY PG TS VPG QPT QGL PC LGN VM GET AF EGL GHID HIVY | 600 |
| | | | . |
| PAX6_HUMAN | 150 | NGQT GS WGT RGP GWY PG TS VPG QPT QGL PC LGN VM GET AF EGL GHID HIVY | 175 |
| GENS CAN pep | 601 | GCQQ QEGG GENT NSISS NGED SDEAQM RLQ LKR K LQR NRT SFT QEQIE AL | 650 |
| | | | |
| PAX6_HUMAN | 176 | GCQQ QEGG GENT NSISS NGED SDEAQM RLQ LKR K LQR NRT SFT QEQIE AL | 225 |
| GENS CAN pep | 651 | EKEFERTHYP DV FARE RLA AKI DL PEARI QVWF SNR RAK W REE KLR NQR | 700 |
| | | | |
| PAX6_HUMAN | 226 | EKEFERTHYP DV FARE RLA AKI DL PEARI QVWF SNR RAK W REE KLR NQR | 275 |
| GENS CAN pep | 701 | RQAS NTP SHI PISS SF STS VY QP IP QP TTP VSS FT SG SML GR TD TA LT NT | 750 |
| | | | |
| PAX6_HUMAN | 276 | RQAS NTP SHI PISS SF STS VY QP IP QP TTP VSS FT SG SML GR TD TA LT NT | 325 |
| GENS CAN pep | 751 | YSAL PPM PSFT MANN LPM QPP VPS QT SS YSC ML PT SP SVN GR SY DT Y TPP | 800 |
| | | | |
| PAX6_HUMAN | 326 | YSAL PPM PSFT MANN LPM QPP VPS QT SS YSC ML PT SP SVN GR SY DT Y TPP | 375 |
| GENS CAN pep | 801 | HMQT HMNS QPM GT SG TT STX | 820 |
| | | | |
| PAX6_HUMAN | 376 | HMQT HMNS QPM GT SG TT STX | 422 |

At this point I would love to suggest you take a look at the PDF and/or postscript images using the links at the top of your results page. Unfortunately, for some time now they have not worked. In compensation, I offer the picture you would get if the links still worked¹³⁵. The pictures are very beautiful, but it should be remembered that making predictions look pretty does not improve their accuracy.

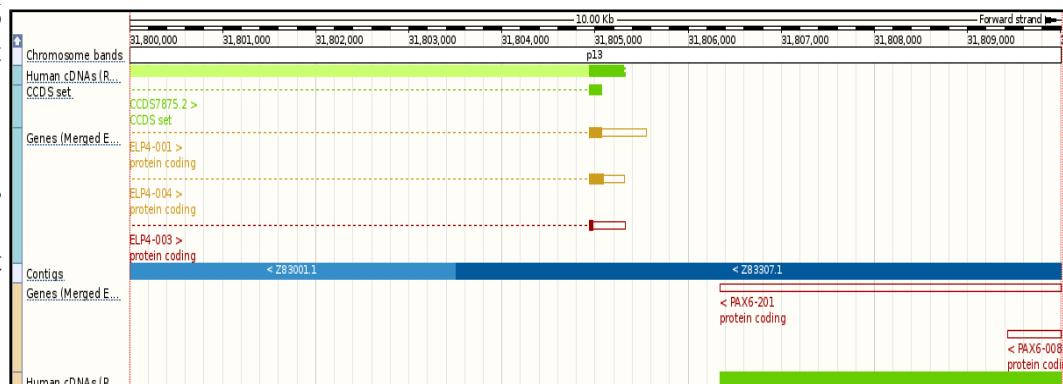


| Gn. | Ex | Type | S | .Begin | ...End | .Len | Fr | Ph | I/Ac | Do/T | CodRg | P.... | Tscr.. |
|------|----|------|---|--------|--------|------|----|----|------|------|-------|-------|--------|
| 1.01 | | Init | + | 5509 | 5600 | 92 | 0 | 2 | 65 | 24 | 139 | 0.462 | 3.17 |
| 1.02 | | Intr | + | 7682 | 8297 | 616 | 2 | 1 | 37 | 65 | 397 | 0.257 | 24.65 |
| 1.03 | | Intr | + | 12000 | 12060 | 61 | 2 | 1 | 96 | 98 | 38 | 0.917 | 3.91 |
| 1.04 | | Intr | + | 12789 | 13073 | 285 | 1 | 0 | 92 | 107 | 50 | 0.900 | 4.61 |
| 1.05 | | Intr | + | 15326 | 15442 | 117 | 0 | 0 | 71 | 52 | 55 | 0.567 | 0.64 |
| 1.06 | | Intr | + | 15628 | 15758 | 131 | 2 | 2 | 141 | 58 | 149 | 0.999 | 17.61 |
| 1.07 | | Intr | + | 16550 | 16591 | 42 | 1 | 0 | 62 | 85 | 51 | 0.608 | 0.64 |
| 1.08 | | Intr | + | 16686 | 16901 | 216 | 2 | 0 | 104 | 94 | 112 | 0.995 | 12.10 |
| 1.09 | | Intr | + | 17606 | 17771 | 166 | 1 | 1 | 76 | 93 | 72 | 0.974 | 6.03 |
| 1.10 | | Intr | + | 17856 | 17927 | 72 | 1 | 0 | 88 | 42 | 58 | 0.553 | 0.58 |
| 1.11 | | Intr | + | 23674 | 23832 | 159 | 2 | 0 | 108 | 54 | 194 | 0.919 | 17.96 |
| 1.12 | | Intr | + | 24348 | 24430 | 83 | 1 | 2 | 29 | 86 | 85 | 0.945 | 1.76 |
| 1.13 | | Intr | + | 24660 | 24810 | 151 | 2 | 1 | 72 | 58 | 76 | 0.958 | 2.74 |
| 1.14 | | Intr | + | 24909 | 25024 | 116 | 1 | 2 | 113 | 108 | 94 | 0.977 | 14.07 |
| 1.15 | | Intr | + | 27602 | 27752 | 151 | 1 | 1 | 115 | 99 | 80 | 0.992 | 11.54 |
| 1.16 | | Term | + | 28405 | 28442 | 38 | 2 | 2 | 68 | 48 | 31 | 0.666 | -5.40 |
| 1.17 | | PlyA | + | 29242 | 29247 | 6 | | | | | | | 1.05 |
| 2.03 | | PlyA | - | 29529 | 29524 | 6 | | | | | | | 1.05 |
| 2.02 | | Term | - | 35069 | 34938 | 132 | 2 | 0 | 74 | 50 | 134 | 0.825 | 6.29 |
| 2.01 | | Intr | - | 38749 | 38623 | 127 | 0 | 1 | 109 | 30 | 61 | 0.727 | 3.08 |

I tried giving Genscan a longer portion of the genomic sequence (an extra 6000 base pairs downstream) and found I got a prediction with a Terminal exon (close, but not quite right) and a polyA. The extra sequence must offer better context.

I also got a partial gene on the opposite strand. A quick look with Ensembl at the region towards the end of the PAX6 suggests this could be the last part of ELP4?

The longer genomic sequence is available if you wish to experiment further (or get it yourself with Ensembl).



Genscan predictions are dependent upon the choice of the set of training sequences used. This website (and all the other Genscan sites I have used) offer a very limited range of training set choices. In the circumstances, the prediction is surprisingly accurate. For serious use, it would be necessary to install Genscan locally and to use customized sets of training data.

¹³⁵ I have asked whether these pictures will ever again be available, I await a reply. So long ago, my expectations have all but expired.

Early Secondary Structure Prediction Methods - GOR

A number of simple methods for investigating protein secondary structure were developed from as far back as the late **1960s**, early **1970s**. Significantly better methods emerged as the **1970s** progressed, claiming accuracy of around **60%** or more. The method we will look at here is one of those improved methods. We will look at the method due to Garnier, Osguthorpe and Robson (**GOR**), originally published in **1978**, but developed/improved well beyond that time. The latest version being **Version V** (published **2002**, a new server announced **2005**). **GOR V** incorporates more modern approaches and has been merged into other prediction strategies. **Wikipedia** offers an informative article on protein secondary structure that is well worth a look if this is an area of particular interest for you.

The older methods, such as **GOR**, are not as accurate as the more modern approaches investigated in the main exercise, however, they do have the advantage of being very quick and easy to run. They provide a reasonable prediction (usually) with little fuss and so still have a role to play, I would suggest.

First a quick glance at the implementation of the **GOR** method in the **EMBOSS** package. This is the method as it was first published. We run it here only to contrast with the better options of the main exercise and more recent version of the same program!

There are a number of ways to access and run the programs of the **EMBOSS** package. Here we will use a web interface called **Emboss Explorer**, as implemented at the **Wageningen Bioinformatics Webportal**, a major Bioinformatics Service Centre of the Netherlands.

Go first to the Wageningen EMBOSS service (<http://emboss.bioinformatics.nl/>).

**PROTEIN 2D
STRUCTURE**
[garnier](#)
[helixturnhelix](#)
[hmoment](#)
[pepcoil](#)
[pepnet](#)
[pepwheel](#)
[tmap](#)
[topo](#)

Select **garnier** from the **PROTEIN 2D STRUTURE** section of the program list.

Use the **Browse** facility To upload a sequence from your local computer. The required sequence is the one in **pax6_human.fasta**. Default parameter settings are fine. Click on the **Run garnier** button.

This version of **GOR** suggests the most likely of four types of secondary structure: Alpha Helices (**H**); Beta Sheets (**E**); Coils (**C**) and Turns (**T**), at each position of the protein sequence.

Some features are composed of only one or two residues. Especially in the case of larger structures such as helices or sheets, such predictions are dubious. Later versions of the algorithm avoid the more foolish predictions.

How credible would you say was the prediction at amino acid 33?

How would you rate the prediction overall? _____

Although the latest version of **GOR** is **GOR V**¹³⁶, **GOR IV**¹³⁷ is more available, reliable and recognisably similar to the original **GOR**. So try **GOR IV** at:

<http://npsa-pbil.ibcp.fr>

Pôle Bioinformatique Lyonnais (PBIL) (Lyons University) offering a wide range of interesting services including a number of ways to predict protein secondary structure. Move down to the **Secondary structure prediction** and click on the link to **GOR IV**. Copy and paste the **PAX6** protein from the file **pax6_human.fasta** into the appropriate text box (just the amino acid codes, this server does not like **fasta** format). Click on the **SUBMIT** button.

GOR IV SECONDARY STRUCTURE PREDICTION METHOD

[Abstract] [NPS@ help] [Original server]

Sequence name (optional) :

Paste a protein sequence below : [help](#)

```
MQNSHSGVNQLGGVFVNGRPLPDSTRKIVELAHSARPDCISRILQVSNGCVSKILGR
YETGSIRPRAIGGSKPRVATPEVVSKIAQYKRECPSIFAWEIRDRLLSEGVCCTNDNIPSV
SSINRVLRLNASEKQMGADGMYDLRMLNGQTGSGWTRPGWYPGTSVPGQOPTQDGCGQQC
EGGGENTNSISNGEDSDEAQMQLQLKRKLQRNRNTSFTQEQUIALEKEFERTHYPDVFARI
ERLAAKIDLPEARIQWFNSRRAKWRREKLRNQRQASNTPSHIPISSSFSTSVDYQPII
QPTTPVSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPPVPSQTSSYSCMLP
SPSVNGRSYDTYTPPHMQTHMNSQPMGTSGTTSTGLISPVGVSVPVQVPGSEPDMSQYWPI
LQ
```

Output width :

SUBMIT **CLEAR**

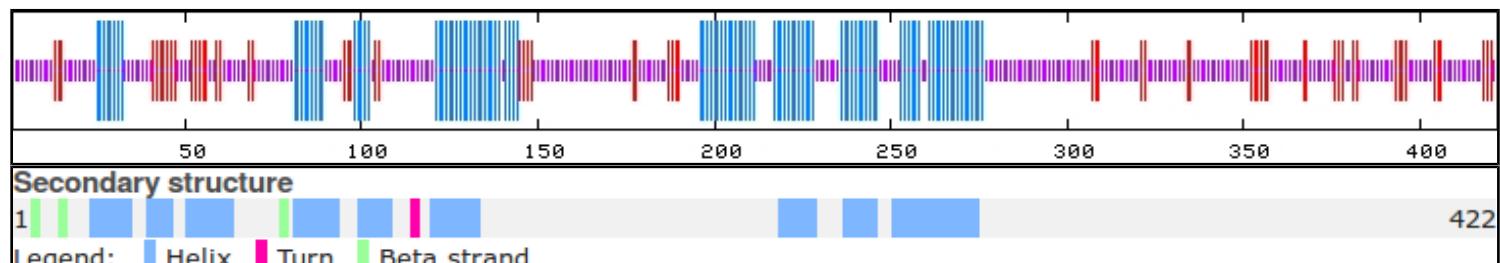
| 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|--|--|----|----|----|----|----|
| | | | | | | |
| MQN SHSGVNQLGGVFVN GRPLPDSTRQKIVELAHSGARPCDI SRLQV SNGCVSKILGRYYETGSIRPRA | cccccccccccccc eeecccccccccc hhhhhhhhcccccccc eeeeeeeeeccc eeeeccc eeeeecccccc eee | | | | | |
| IGGSKPRVATPEVVSKIAQYKRECPSIFAWEIRDRLLSEGVTNDNIPSVSSINRVLRLNASEKQQMGAD | cccccccccccccc hhhhhhhhcccc eeehhhcc eeecccccccccccccc hhhhhhhhcccccccccc hhhhhhhh | | | | | |
| GMYDKLRLMLNGQTGSWGTRPGWPGTSVPQGQPTQDGQQEGGGENTNSI S SNGEDSDEAQMRLQLKRKL | c hhhheeeecc | | | | | |
| QRNRTSFTQEQUIALEKEFERTHYPDVFARERLAAKIDLPEARIQVWF SNRRAKWRREEKLRNQRRQASN | hhcccccc hhhhhhhhcc | | | | | |
| TPSHIPISSSFSTS VYQPI PQPTT PVS SFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPPVPSQ | cc | | | | | |
| TSSYSCMLPTSPSVNGRSYDTYTPPHMQTHMNSQPMGTSGTTSTGLI SPGVSVPVQVPGSEPDMSQYWPR | c eeeeeeecccccccccc eeecccccccccc eeecccccccccc eeecccccccccc eeecccccccccc eee | | | | | |
| LQ | ec | | | | | |

GOR IV, unlike the **EMBOSS garnier** program (**GOR I**), does not try to differentiate between Coil and Turn. It chooses for each position the most likely from Helix, Extended (i.e. beta sheet) or unstructured (i.e. Coil).

Also unlike the initial **GOR** implementation of the **garnier** program, **GOR IV** only predicts helices of at least four residues and beta sheets of at least two residues.

How does the prediction at position 33 compare with that of garnier?

Further down your output is a graphic showing how the structure predictions are positioned along the protein sequence. This can usefully be compared to part of the graphic you considered earlier, showing where these features lie in the view of **Uniprot**.



How would you rate the prediction overall?

¹³⁶ Read all about it at: <http://bioinformatics.oxfordjournals.org/cgi/content/full/21/11/278>.

137 J. Garnier, J.F. Gibrat and B.Robson in *Methods in Enzymology*, vol 266, p 540-553 (1996). GOR IV uses a data base of 267 proteins to validate its predictions which it claims to have a mean accuracy of 64.4% for a three state prediction (H, E or C).

Domain & Motif prediction with Prosite, Pfam, HTH & PRINTS

In this supplementary exercise, we will search for **protein sequence motifs** and **protein domains** using individual database searches and specific simple specialised software. Just in case you still have doubts, I have linked the references above to the wikipedia pages that clearly define both motifs and domains in this context. You may have gathered, I am a big fan of **Wikipedia**.



Searching

A major database for both motifs and domains is **PROSITE**. Many sequence motifs in this database are described using a simple pattern description language. They include some very common, simple motifs, many only a few residues long, that indicate possible sites for post-translational modifications (e.g. glycosylation or phosphorylation).

Go to the **ExPASy**¹³⁸ site at:

http://www.expasy.org

Select **proteomics** from the list of **Categories**. Select **PROSITE** from the **Databases** section. Click on the **ScanProsite** link at the top of your page.

Categories

- proteomics**
 - protein sequences and identification
 - mass spectrometry and 2-DE data
 - protein characterisation and function
 - families, patterns and profiles
 - post-translational modification
 - protein structure
 - protein-protein interaction
 - similarity search/alignment
 - genomics
 - structural bioinformatics
 - systems biology

Databases

- UniProtKB** • functional information on proteins • [\[more\]](#)
- UniProtKB/Swiss-Prot** • protein sequence database • [\[more\]](#)
- STRING** • protein-protein interactions • [\[more\]](#)
- SWISS-MODEL Repository** • protein structure homology models • [\[more\]](#)
- PROSITE** • protein domains and families • [\[more\]](#)
- ViralZone** • portal to viral UniProtKB entries • [\[more\]](#)
- neXtProt** • human proteins • [\[more\]](#)

STEP 1 - Submit PROTEIN sequences [\[help\]](#)

Submit PROTEIN sequences (max. 10) [\[Examples\]](#)

Submit a PROTEIN database (max. 16MB) for repeated scans (The data will be stored on our server for 1 month).

```
Psp|P26367|PAX6_HUMAN Paired box protein Pax-6;
M01HSGVNULGIVVNIGPLPSTRKICVLHSGAPCDISRLIVSNGCVSKILGRY
YETGSIKPRAIGSSPKPVATPEVSKIAIAYKRECPSPFAMEIPIRLLSEGVNTIPSV
SS1NVLNLASEKIQMNGADQYDVKLPMIINCQTSNSGCTRGWYPGTSVQQTDTGDC000
EGGEGENTNSSSNGEDSDEADMRLULPKKLDRNRTSFTEOIEALEKEFERTHYPOVFAE
ERLAAKDOLPEARL0WIFSNRAAMIRREKELRNVRQR0A5NTPSHPTSSSFSTSYVQPTP
QPTPPVSFTGGSNLGRDTALTHYTSLPPMSFMANNPQ0PVPVPSQTSSYQSLDPT
SPSVWGHGSYDYYTTPHRI0HNSUPGTSGT1TG1SPGOSVPU0VPGSEPDS0WES
LQ
```

Supported input:

- UniProtKB accessions e.g. P98073 or identifiers e.g. ENTK_HUMAN
- PDB identifiers e.g. 4DGJ
- Sequences in FASTA format

STEP 2 - Select options [\[help\]](#)

Exclude motifs with a high probability of occurrence from the scan

Exclude profiles from the scan

Run the scan at high sensitivity (show weak matches for profiles)

In the **STEP 2 - Select options** section, ensure that the **Exclude motifs with a high probability of occurrence** box is ticked.

The defaults offered in the **STEP 3 - Select output options and submit your job** section are fine so just click on the **START THE SCAN** button. In but a few moments, your results will burst forth.

STEP 3 - Select output options and submit your job

Output format: [Graphical view](#)

Retrieve complete sequences: If you choose this option, not all output formats are available.

Receive your results by email

START THE SCAN **Reset**

¹³⁸ ExPASy is a major site for protein based research in Switzerland. As the all knowing Wikipedia puts it:

“ExPASy is a **bioinformatics** resource portal operated by the Swiss Institute of Bioinformatics (**SIB**) and in particular the **SIB Web Team**. It is an extensible and integrative portal accessing many scientific resources, databases and software tools in different areas of life sciences. Scientists can access a wide range of resources in many different domains, such as **proteomics**, **genomics**, **phylogeny/evolution**, **systems biology**, **population genetics**, and **transcriptomics**.”

hits by profiles: [2 hits (by 2 distinct profiles) on 1 sequence]

Upper case represents match positions, lower case insert positions, and the '-' symbol represents deletions relative to the matching profile.

ruler: 1 100 200 300 400 500 600 700 800 900 1000

USERSEQ1 PAIRED_2 HOMEBOX_2 (422 aa)

PS51057 PAIRED_2 Paired domain profile :

4 - 130: score = 64.941
SHSGVNQLGGVVFVNQGRPLPDSTROKIVELAHSGARPCDISRILQVSNGCVSKILGRYYET
GSIQRRAIGSGKPRVATPEVSKIAQYKRECPSPFIAWEIRDRLSEGVCNTNDNIPSVSSI
NRVLRLNL

Predicted feature:

| DOMAIN | 4 | 130 | Paired | [condition: none] |
|---|------------|----------------|--|-------------------|
| PS50071 HOMEBOX_2 'Homeobox' domain profile : | 208 - 268: | score = 20.164 | RKLQRNRNTSFTQEQQIEALEKEFERHYPDVFAERLAAKIDLPEARIQVWFSNRRAKWRR | E |

Two hits with **PROSITE** patterns confirming the same domains by matching their highly conserved subregions. Confirmation of what has already been discovered more than once, but this time, discovered by running a database search program manually. Exactly this program was used to generate the annotation read earlier.

hits by patterns: [2 hits (by 2 distinct patterns) on 1 sequence]

ruler: 1 100 200 300 400 500 600 700 800 900 1000

USERSEQ1 (422 aa)

PS00034 PAIRED_1 Paired domain signature :

38 - 54: [confidence level: (0)] RPCdisrilqvsngCVS

PS00027 HOMEBOX_1 'Homeobox' domain signature :

243 - 266: [confidence level: (0)] LaakIdLPeaRIQVWFsNrakwR

Move back to the search submission page. In Step 2, deselect **Exclude patterns with a high probability of occurrence**. START THE SCAN again.

| PS00008 MYRISTYL N-myristoylation site : | |
|--|--------|
| 13 - 18: | GVfvNG |
| 36 - 41: | GArpCD |
| 110 - 115: | GVctND |
| 151 - 156: | GTtgSW |
| 154 - 159: | GSwgTR |
| 157 - 162: | GTtpGW |
| 182 - 187: | GGgeNT |
| 183 - 188: | GGenTN |
| 312 - 317: | GSmlGR |
| 387 - 392: | GTsgTT |
| 390 - 395: | GTtsTG |

hits by patterns with a high probability of occurrence or by user-defined patterns: [19 hits (by 5 distinct patterns) on 1 sequence]

ruler: 1 100 200 300 400 500 600 700 800 900 1000

sp-P26367-
PAX6_HUMAN
(sp-P26367-PAX
6_HUMAN) (422 aa)

This time you will see many more hits with patterns.

Follow the link to the documentation for an **N-myristoylation site (PS00008)**.

What is the signature pattern for **N-myristoylation site**? _____

How would you interpret this pattern? _____

How many **N-myristoylation** sites did **ScanProsite** suggest there might be in **PAX6_HUMAN**? _____

How many **real N-myristoylation** sites would you guess there might be in **PAX6_HUMAN**? _____

Searching Pfam

Go to the home of **Pfam** at:

<http://pfam.sanger.ac.uk/>

Select the **VIEW A SEQUENCE** option. Enter **pax6_human** (or the corresponding accession code) into the proffered space and press the **Go** button. You will be taken to the sequence and offered links to view (again) typical 3D structures for the domains of this protein. Also, you are offered the opportunity to generate easily a phylogenetic tree based upon **PAX6** from the **TreeFam** database, which is fun if nothing else. We will not be seriously covering phylogeny in the course of these exercises, but why not try it anyway by clicking on the **TreeFam** link.

Fine, but you are just looking at what has already been decided. Here we set out to discover, by analysis. How could you use **Pfam** for a sequence that has yet to be annotated.

Go back to the home of **Pfam** at:

<http://pfam.sanger.ac.uk/>

This time select the **SEQUENCE SEARCH** option. Copy and paste the sequence of **PAX6_HUMAN** into the appropriate box. Click on the **Go** button.

You should discover nothing you did not expect. This same conclusions, but via investigation of the sequence rather than database lookup.

| Significant Pfam-A Matches | | | | | | | | | | | | | | |
|---|---------------------|------------|------------------------|----------|-----|-----------|-----|------|-----|------------|-----------|---------|------------------------|-------------------------------------|
| Show or hide all alignments . | | | | | | | | | | | | | | |
| Family | Description | Entry type | Clan | Envelope | | Alignment | | HMM | | HMM length | Bit score | E-value | Predicted active sites | Show/hide alignment |
| | | | | Start | End | Start | End | From | To | | | | | |
| PAX | 'Paired box' domain | Domain | CL0123 | 4 | 128 | 4 | 128 | 1 | 125 | 125 | 238.8 | 8.5e-72 | n/a | Show |
| Homeobox | Homeobox domain | Domain | CL0123 | 211 | 267 | 212 | 267 | 2 | 57 | 57 | 79.7 | 9.3e-23 | n/a | Show |

Have a look around generally, but in the course of your investigations, Click on one of the **CL0123** links. You will see that both the **PAX** and **Homeobox Pfam** families belong to a collection of families (a **Clan**) all of which contain **helix-turn-helix** motifs and are mostly involved in DNA binding. Unsurprisingly, the clan in question is the **Helix-turn-helix** clan.

Would you have found anything of interest had you chosen “to search for Pfam-B matches” (you will need to run the search again in order to answer this one)? _____

Searching for Helix-Turn-Helix motifs

When looking at the **Prosite PAX** and **homeobox** documentation earlier, you will have recorded three positions where there should be **Helix-Turn-Helix** motifs that bind the DNA major groove. The **EMBOSS** package includes a program, **helixturnhelix**, that searches for these motifs. **helixturnhelix**¹³⁹ uses a scoring matrix derived from alignments of known **HTH** motifs. The original matrix of 1987 looked for motifs spanning 20 amino acids, the later (1990) improved matrix was based on an alignment of 91 **HTH** motifs and was 22 amino acids wide.

There are a number of ways to access and run the programs of the **EMBOSS** package. Here we will use a web interface called **Emboss Explorer**, as implemented at the **Wageningen Bioinformatics Webportal**, a major Bioinformatics Service Centre of the Netherlands.

PROTEIN 2D STRUCTURE
[garnier](#)
[helixturnhelix](#)
[hmoment](#)
[pepcoil](#)
[pepnet](#)
[pepwheel](#)
[tmap](#)
[topo](#)

Go first to the **Wageningen EMBOSS service** (<http://emboss.bioinformatics.nl/>). Select **helixturnhelix** from the **PROTEIN 2D STRUCTURE** section of the list of programs.

Use the **Browse** facility **To upload a sequence from your local computer**. The required sequence is the one you saved in the file **pax6_human.fasta**, of course. The default parameter settings are fine for a first try. Click on the **Run helixturnhelix** button.

helixturnhelix will suggest just one part of the sequence that might be a **Helix-Turn-Helix**.

To which, if any, of the expected **HTH** motifs does this prediction correspond? _____

```
#=====
#
# Sequence: PAX6_HUMAN      from: 1      to: 422
# HitCount: 1
#
# Hits above +2.50 SD (972.73)
#
#=====

Maximum_score_at at "*""

(1) Score 1109.000 length 22 at residues 238->259
      *
Sequence: FARERLAAKIDLPEARIQVWFS
           |           |
238             259

Maximum_score_at: 238
Standard_deviations: 2.96
```

```
#=====
#
# Sequence: PAX6_HUMAN      from: 1      to: 422
# HitCount: 2
#
# Hits above +2.50 SD (972.73)
#
#=====

Maximum_score_at at "*""

(1) Score 1086.000 length 20 at residues 39->58
      *
Sequence: PCDISRILQVSNGCVSKILG
           |           |
39             58

Maximum_score_at: 39
Standard_deviations: 2.89

(2) Score 1028.000 length 20 at residues 240->259
      *
Sequence: RERLAAKIDLPEARIQVWFS
           |           |
240            259

Maximum_score_at: 240
Standard_deviations: 2.69
```

As the expectation was that three **HTH** motifs might be found, try again. This time, in the Additional Section of **heleixturnhelix**'s menu window, choose to **Use the old (1987) weight data**.

This time you will find **2 HTH** motifs, essentially the one you found previously, plus another. Note that the length of the predictions have shrunk from **22 amino acids** to **20**.

To which, if any, of the expected **HTH** motifs does the new prediction correspond? _____

¹³⁹ This method is described in: Dodd I.B., Egan J.B. (1987) "Systematic method for the detection of potential lambda cro-like DNA-binding regions in proteins." *J. Mol. Biol.* 194: 557-564. Revised in Dodd I.B., Egan J.B. (1990) "Improved detection of helix-turn-helix DNA-binding motifs in protein sequences." *Nucleic Acids Res.* 18: 5019-5026.

You can download the more recent paper from: <http://nar.oxfordjournals.org/cgi/reprint/18/17/5019.pdf>

It seems a bit odd to get the better result from the older scoring matrix, so try once more, using the default scoring matrix. This time, in the **Additional section**, set the **Minimum SD to 2.0** before you click **OK**.

```
#=====
#
# Sequence: PAX6_HUMAN      from: 1    to: 422
# HitCount: 2
#
# Hits above +2.00 SD (825.93)
#
#=====

Maximum_score_at at **"

(1) Score 1109.000 length 22 at residues 238->259
    *
Sequence: FARERLAAKIDLPEARIQVWFS
    |           |
  238         259

Maximum_score_at: 238
Standard_deviations: 2.96

(2) Score 827.000 length 22 at residues 37->58
    *
Sequence: ARPCDISRILQVSNGCVSKILG
    |           |
  37         58

Maximum_score_at: 37
Standard_deviations: 2.00
```

By asking to see hits just 2 standard deviations away from the average (random) score, you see a second reasonable prediction. Lowering your standards further will be to no avail with either scoring matrix. Either the third suggested HTH is not present in **PAX6_HUMAN**, or **helixturnhelix** is simply not sufficiently clever to find it.

Can you suggest anything particular about the third putative HTH motif that might explain its reluctance to be discovered? _____

PRINTS

Searching

The **PRINTS** database defines functional protein families. Domains are identified by a number of short, ordered, well-conserved regions. A full match to one of these “fingerprints” will match all the relevant short regions in the correct order. A partial match is recorded if some are missing or if they occur in an incorrect order. **PRINTS** can be searched using the **fingerPRINTscan** program.

Go to the **fingerPRINTscan** home page:

<http://umber.sbs.man.ac.uk/fingerPRINTScan/>

Select the **FPScan** link¹⁴⁰ and paste in the **PAX6_HUMAN** sequence in raw format. Leave all defaults and hit the **Send Query** button.

| Highest scoring fingerprints for your query | | | |
|---|--------------|-------------------------|---------|
| Fingerprint | E-value | GRAPHScan | Motif3D |
| PAIREDBOX (relations) | 1.499643e-43 | Graphic | |

The top hit is with the **PAIREDBOX** fingerprint. No surprise here. Move down to the list of the best **10** hits.

| Ten top scoring fingerprints for your query | | | | | | | | | |
|--|------------------------------|---------------|---------|-------|---------|---------|---------|-----------|-------------------------|
| Ancestry | Fingerprint | No. of Motifs | SumId | AveId | PfScore | Pvalue | Evalue | GRAPHScan | |
| PAIREDBOX | PAIREDBOX | 4 of 4 | 3.5e+02 | 87 | 3213 | 1.3e-49 | 1.5e-43 | | Graphic |
| HTHREPRESSR | HTHREPRESSR | 2 of 2 | 75.92 | 37.96 | 586 | 5.3e-08 | 0.17 | II | Graphic |
| POUDOMAIN | POUDOMAIN | 2 of 5 | 65.80 | 32.90 | 577 | 1.7e-07 | 0.39 | ...II | Graphic |
| HOMEobox | HOMEobox | 2 of 3 | 102.06 | 51.03 | 724 | 3e-07 | 1.2 | .II | Graphic |
| PRICHEXTENSN | PRICHEXTENSN | 3 of 8 | 102.84 | 34.28 | 664 | 1.2e-05 | 20 | .iii.... | Graphic |
| POAALLERGEN | POAALLERGEN | 2 of 8 | 42.41 | 21.20 | 393 | 7e-05 | 1.7e+02 |i.i | Graphic |
| 7TM->GPCRCLAN->GPCRRHODOPSN->LTBRECEPTOR->LTB1RECEPTOR | LTB1RECEPTOR | 2 of 6 | 71.96 | 35.98 | 371 | 0.00032 | 8.4e+02 | .i..i.. | Graphic |
| PROTEINF153 | PROTEINF153 | 2 of 5 | 52.81 | 26.40 | 458 | 0.00038 | 6.9e+02 | i...i | Graphic |
| ACONITASE | ACONITASE | 2 of 9 | 63.61 | 31.80 | 336 | 0.00047 | 1.5e+03 |ii. | Graphic |
| GLIADGLUTEN->GLIADIN | GLIADIN | 2 of 9 | 73.82 | 36.91 | 396 | 0.0013 | 3.7e+03 | .i.....I | Graphic |

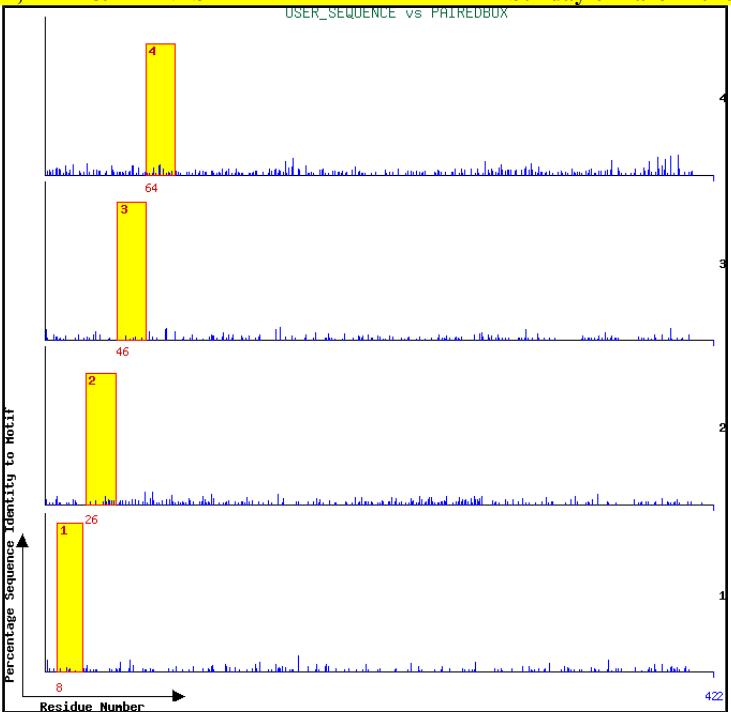
In the list of **Ten top scoring fingerprints**, there is a second **fingerprint** that matches all elements in the correct order. This is the **HTHREPRESSR**. Click on the **HTHREPRESSR** link and from the documentation you can confirm that an **HTHREPRESSOR** is an **HTH** motif of the sort detected by the **EMBOSS** program **helixturnhelix**. Move back to your **fingerPRINTscan** results.

| Ten top scoring fingerprints for your query. Detailed by motif | | | | | | | | | |
|--|--------------|---------|---------|----------|---------------------|--------|-----|-----|------|
| FingerPrint Name | Motif Number | IdScore | PfScore | Pval | Sequence | Length | low | Pos | high |
| PAIREDBOX | 1 of 4 | 93.82 | 815 | 1.0le-12 | VNQLGGVFVNGRPLPD | 16 | 0 | 8 | 0 |
| | 2 of 4 | 82.91 | 821 | 6.08e-13 | RQKIVELAHSGARPCDISR | 19 | 0 | 26 | 0 |
| | 3 of 4 | 87.39 | 809 | 2.95e-12 | LQVSNGCVSKILGRYYET | 18 | 0 | 46 | 0 |
| | 4 of 4 | 83.08 | 768 | 6.99e-14 | GSIRPRAIGGSKPRVATP | 18 | 0 | 64 | 0 |
| HTHREPRESSR | 1 of 2 | 32.91 | 134 | 3.98e-02 | ARERLAAKID | 10 | 0 | 239 | 0 |
| | 2 of 2 | 43.00 | 452 | 1.34e-06 | DLPEARIQVWFNSNRRAK | 17 | 0 | 248 | 0 |

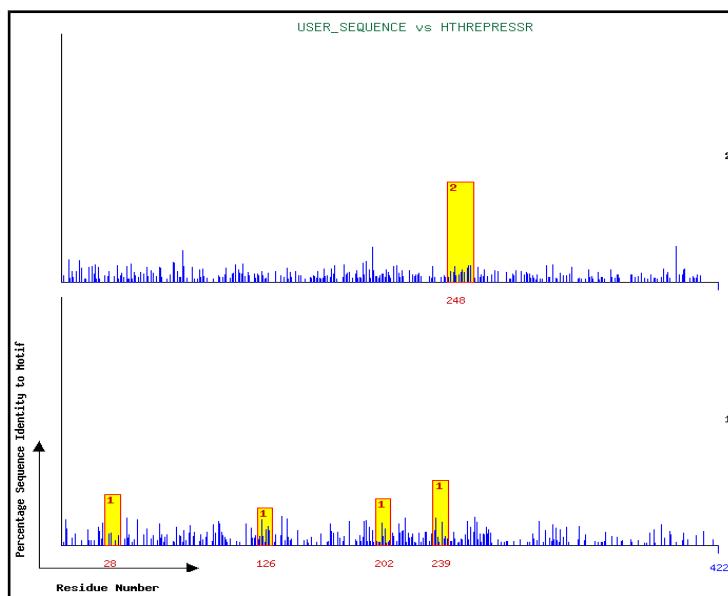
From the Position information included in the **Detailed by motif** table, you can see that the **HTH** motif that **fingerPRINTscan** finds is the same one that the **EMBOSS** program **helixturnhelix** found with default settings.

140 Alternatively you can use the mirror at the EBI <http://www.ebi.ac.uk/printsscan/>

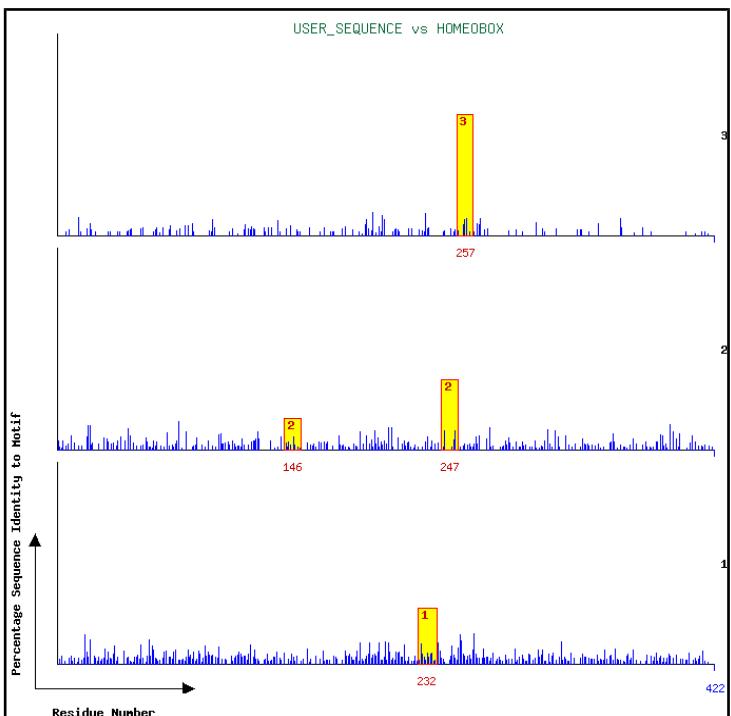
Take a look at the **GRAPHScan** for the **PAIREDBOX** prediction and see that is is good! Four out of four very positive motif matches are shown.



Each motif by itself might not be significant. Together, in a **fingerprint**, they constitute a confident prediction for a **Paired Box domain**.



Click on the **Graphic** link for the **HTHREPRESSOR** hit. The best (highest) of the four **motif 1** hits plus the single **motif 2** hit is the finger print that justifies the **HTHREPRESSOR** prediction.



Move back to the **Ten top scoring fingerprints** table. Notice that, whilst there is a prediction for a **HOMEobox**, it is an incomplete prediction. Only two of the required motifs were detected and so no prediction of a **HOMEobox** would have been made automatically by **fingerPRINTscan**. This explains why there is no **PRINTS** prediction for a **HOMEobox** in the **Uniprot Feature Table** for **PAX6_HUMAN**.

However, if you click on the **Graphics** link for the “2 out of 3” motif hit for **homeobox**, you will see that **fingerPRINTscan** only missed the **HOMEobox** by a whisker!

From the Top ten scoring fingerprints table, you can see that **fingerPRINTscan** considers the first motif to be missing (“.II”). But I can see a fairly healthy motif 1 in the graphic. I think I would be inclined to give the **HOMEobox** the benefit of the doubt, would you not? Programs can be so very picky!!! Its a hit



Model Answers to Questions in the Instructions Text.

Notes:

For the most part, these “**Model Answers**” just provide the reactions/solutions I hoped you would work out for yourselves. However, sometime I have tried to offer a bit more background and material for thought? Occasionally, I have rambled off into some rather self indulgent investigations that even I would not want to try and justify as pertinent to the objective of these exercises. I like to keep these meanders, as they help and entertain me, but I wish to warn you to only take regard of them if you are feeling particularly strong and have time to burn. Certainly not a good idea to indulge here during a time constrained course event!

Where things have got extreme, I am going to make two versions of the answer. One starting:

Summary:

Which has the answer with only a reasonably digestible volume of deep thought. Read this one.

The other will start:

Full Answer:

Beware of entering here! I do not hold back. Nothing complicated, but it will be long and full of pedantry.

This makes the Model answers section very big. **BUT**, it is not intended for printing or for reading serially, so I submit, being long and wordy does not matter. Feel free to disagree.

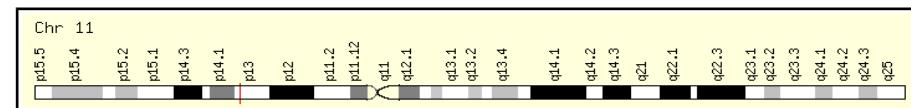
From your investigations using GeneCards:

What do you conclude to be the gene most relevant to **aniridia**?

The gene most relevant to the keyword **aniridia** is **PAX6**. I imagine, in “real life”, one might take an interest (with good reason, as you will see) in some of the other significantly scoring genes. However, this is but an exercise, in which the complexities of reality can be shovelled to one side whenever it suits. So **PAX6** it is then!

Properties suggested by **GeneCards** for the gene of interest were:

Cytogenetic location.



The Cytogenetic location of **PAX6** is shown as **11p13**

Three sources are quoted for this information, **Ensembl**, **Entrez Gene** and **HGNC**. Happily, and expectedly for such a basic prediction, they all agree.

Number of **UniProt** isoforms.

Protein details for PAX6 Gene (UniProtKB/Swiss-Prot)

Protein Symbol: P26367-PAX6_HUMAN Recommended name: Paired box protein Pax-6
Protein Accession: P26367 Secondary Accessions: Q6N006 Q99413

Protein attributes for PAX6 Gene

Size: 422 amino acids
Molecular mass: 46683 Da
Quaternary structure:
Interacts with MAF and MAFB. Interacts with TRIM11; this interaction leads to ubiquitination and proteasomal degradation, as well as inhibition of transactivation, possibly in part by preventing PAX6 binding to consensus DNA sequences.

Three dimensional structures from OCA and Proteopedia for PAX6 Gene

2CUE (3D) 6PAX (3D)

Alternative splice isoforms for PAX6 Gene

UniProtKB/Swiss-Prot: P26367-1 P26367-2 P26367-3

3 isoforms are suggested by the **UniProtKB** protein sequence database.

How many transcripts are predicted by matches to mRNAs in REFSEQ?

Summary:

(24) REFSEQ mRNAs : NM_000280.4 NM_001127612.1 NM_001258462.1 NM_001258463.1 NM_001258464.1 NM_001258465.1 NM_001310158.1
NM_001310159.1 NM_001310160.1 NM_001310161.1 NM_001604.5 XM_005252954.3 XM_005252955.3 XM_005252956.3 XM_005252958.3
XM_006718246.2 XM_011520146.1 XM_011520147.1 XM_011520148.1 XM_011520149.1 XM_011520150.1 XM_011520151.1 XM_011520152.1
XM_011520153.1 See Less »

There are **24** matches of the **PAX6** gene with **mRNAs** in **REFSEQ** implying **24** alternative transcripts.

Full Answer:

REFSEQ proteins: NP_000271.1 NP_001121084.1 NP_001245391.1 NP_001245392.1 NP_001245393.1 NP_001245394.1 NP_001297087.1
NP_001297088.1 NP_001297089.1 NP_001297090.1 NP_001595.2

In the **Protein Section**, only **11** **REFSEQ** proteins are reported? But every protein coding **RefSeq** transcript/mRNA has an associated (not necessarily unique) **RefSeq** protein? So **11 RefSeq** proteins implies only **11** alternative **RefSeq** transcripts, which contradicts the assertion of **24** above?

Until fairly recently, the two reports **did** agree because **GeneCards** only reported the **RefSeq** mRNAs whose accession codes commenced with **NM_** (of which there are exactly **11**). These are slightly better evidenced than the remaining **13** whose accession codes commenced with **XM_**. The **NM_** transcripts correspond **1 to 1** with the (reported) **RefSeq** proteins whose accession codes commence **NP_**. The **XM_** transcripts correspond **1 to 1** with (unreported) **RefSeq** proteins whose accession codes commence **XP_**.

Now **GeneCards** have decided to report the less well evidenced mRNAs (whose accession codes begin **XM_**) but still not to report their corresponding **RefSeq** proteins (which do exist and whose accession codes begin **XP_**). Hence the seemingly illogical discrepancy between the two reports.

It maybe **GeneCards** has a good reason to only report **NP_** proteins? Or, it could be a mistake. I go for the mistake theory. I have asked and received the response below, which supports the mistake theory I suggest.

NP_ proteins and **XP_** proteins comes from different sections of **RefSeq**. This is explained in the manual as illustrated.

Definitions:

- **Model RefSeq**: RNA and protein products that are generated by the eukaryotic genome annotation pipeline. These records use accession prefixes **XM_**, **XR_**, and **XP_**.
- **Known RefSeq**: RNA and protein products that are mainly derived from GenBank cDNA and EST data and are supported by the RefSeq eukaryotic curation group. These records use accession prefixes **NM_**, **NR_**, and **NP_**.

For now, consider just the **11 NP_** proteins reported.

As noted above, **11 RefSeq** proteins does not imply **11** distinct protein sequences. **RefSeq** translates the coding regions of all **11 RefSeq mRNA** sequences and records the results, even if most are identical. In this case, there really should be at most **3** distinct protein sequence possibilities, given that **UniprotKB** predicts just **3** isoforms.

To illustrate the veracity of this claim, I have retrieved all **11 RefSeq PAX6** protein from the databases at the **NCBI** and multiply aligned them with a program called **COBALT** (again at the **NCBI**). I did this using strategies very similar to those you will investigate in the next few pages of these exercises.

The resultant alignment (see below) used to only include the top **7** proteins. When this was true, I was able to claim that you should be able to see that just **2** distinct proteins are evident (a 14 amino acid **Insertion/Deletion** near the start of the protein being the only difference). Why there were only **2**, rather than the promised **3** distinct sequences will become clear shortly.

Now, as is so tediously often the case, **4** more proteins have emerged, according to **RefSeq**. **3** of these dare to upset the poetry of my interpretations! I retire in petulance. **Uniprot** actually claims there are **2** proteins of known sequence and **1** of unknown sequence. The current alignment suggests there are **4** isoforms, all of known sequence? Well, it is acceptable to disagree, these conclusions are all only predictions after all.

So, I hear you ask, why pursue this sort of issue to such depth? It is not really important unless you are really researching **PAX6** and/or **aniridia**. **TRUE!** but the more general objective is to expose the fact that sometimes the discrepancies/anomalies you will come across are not due to alternative biological interpretations but to the way the various information resources are administered.

Plus, of course, I am an incorrigible pedant and cannot leave alone the minutiae, however minute they may be.

| | | | |
|--|-----|---|-----|
| <input checked="" type="checkbox"/> NP_001245394 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQ-----VSNGCVSKILGRYYETGSI | 66 |
| <input checked="" type="checkbox"/> NP_001245393 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQ-----VSNGCVSKILGRYYETGSI | 66 |
| <input checked="" type="checkbox"/> NP_001121084 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQ-----VSNGCVSKILGRYYETGSI | 66 |
| <input checked="" type="checkbox"/> NP_001595 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQTHADAKVQVLNDNQNVNSNGCVSKILGRYYETGSI | 80 |
| <input checked="" type="checkbox"/> NP_001297087 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQTHADAKVQVLNDNQNVNSNGCVSKILGRYYETGSI | 80 |
| <input checked="" type="checkbox"/> NP_001245392 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQTHADAKVQVLNDNQNVNSNGCVSKILGRYYETGSI | 80 |
| <input checked="" type="checkbox"/> NP_001245391 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQTHADAKVQVLNDNQNVNSNGCVSKILGRYYETGSI | 80 |
| <input checked="" type="checkbox"/> NP_001297088 | 1 | MQNHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRLQ-----VSNGCVSKILGRYYETGSI | 66 |
| <input checked="" type="checkbox"/> NP_001297090 | | ----- | |
| <input checked="" type="checkbox"/> NP_001297089 | | ----- | |
| <input checked="" type="checkbox"/> NP_001245394 | 67 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 146 |
| <input checked="" type="checkbox"/> NP_001245393 | 67 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 146 |
| <input checked="" type="checkbox"/> NP_001121084 | 67 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 146 |
| <input checked="" type="checkbox"/> NP_001595 | 81 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 160 |
| <input checked="" type="checkbox"/> NP_001297087 | 81 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 160 |
| <input checked="" type="checkbox"/> NP_001245392 | 81 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 160 |
| <input checked="" type="checkbox"/> NP_001245391 | 81 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 160 |
| <input checked="" type="checkbox"/> NP_001297088 | 67 | RPRAIGGSKPRVATPEVVSKIAQYKRECPEIFWEIRDRLSEGVCNDNIPSVSSINRVLRLASEKQQMGADGMYDKL | 146 |
| <input checked="" type="checkbox"/> NP_001297090 | 1 | -----MGADGMYDKL | 10 |
| <input checked="" type="checkbox"/> NP_001297089 | 1 | -----MGADGMYDKL | 10 |
| <input checked="" type="checkbox"/> NP_001245394 | 147 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 226 |
| <input checked="" type="checkbox"/> NP_001245393 | 147 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 226 |
| <input checked="" type="checkbox"/> NP_001121084 | 147 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 226 |
| <input checked="" type="checkbox"/> NP_001595 | 161 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 240 |
| <input checked="" type="checkbox"/> NP_001297087 | 161 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 240 |
| <input checked="" type="checkbox"/> NP_001245392 | 161 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 240 |
| <input checked="" type="checkbox"/> NP_001245391 | 161 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 240 |
| <input checked="" type="checkbox"/> NP_001297088 | 147 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 226 |
| <input checked="" type="checkbox"/> NP_001297090 | 11 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 90 |
| <input checked="" type="checkbox"/> NP_001297089 | 11 | RMLNGQTGSWGTRPGWYGPGSTVPGQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRQLKRLQRNLRTSFTQEQUIALE | 90 |
| <input checked="" type="checkbox"/> NP_001245394 | 227 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 306 |
| <input checked="" type="checkbox"/> NP_001245393 | 227 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 306 |
| <input checked="" type="checkbox"/> NP_001121084 | 227 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 306 |
| <input checked="" type="checkbox"/> NP_001595 | 241 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 320 |
| <input checked="" type="checkbox"/> NP_001297087 | 241 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 320 |
| <input checked="" type="checkbox"/> NP_001245392 | 241 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 320 |
| <input checked="" type="checkbox"/> NP_001245391 | 241 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 320 |
| <input checked="" type="checkbox"/> NP_001297088 | 227 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 306 |
| <input checked="" type="checkbox"/> NP_001297090 | 91 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 170 |
| <input checked="" type="checkbox"/> NP_001297089 | 91 | KEFERTHYPDVFAKERLAAKIDLPEARIQVWFNSRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSVYQPIPQPTTPV | 170 |
| <input checked="" type="checkbox"/> NP_001245394 | 307 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 386 |
| <input checked="" type="checkbox"/> NP_001245393 | 307 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 386 |
| <input checked="" type="checkbox"/> NP_001121084 | 307 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 386 |
| <input checked="" type="checkbox"/> NP_001595 | 321 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 400 |
| <input checked="" type="checkbox"/> NP_001297087 | 321 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 400 |
| <input checked="" type="checkbox"/> NP_001245392 | 321 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 400 |
| <input checked="" type="checkbox"/> NP_001245391 | 321 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 400 |
| <input checked="" type="checkbox"/> NP_001297088 | 307 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 386 |
| <input checked="" type="checkbox"/> NP_001297090 | 171 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 250 |
| <input checked="" type="checkbox"/> NP_001297089 | 171 | SSFTSGSMLGRTDTALTNTYSALPPMPSFTMANNLPMQPQPVPSQTSSYSCMLPTSPSVNGRSYDTPPHMQTHMNSQPM | 250 |
| <input checked="" type="checkbox"/> NP_001245394 | 387 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 422 | |
| <input checked="" type="checkbox"/> NP_001245393 | 387 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 422 | |
| <input checked="" type="checkbox"/> NP_001121084 | 387 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 422 | |
| <input checked="" type="checkbox"/> NP_001595 | 401 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 436 | |
| <input checked="" type="checkbox"/> NP_001297087 | 401 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 436 | |
| <input checked="" type="checkbox"/> NP_001245392 | 401 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 436 | |
| <input checked="" type="checkbox"/> NP_001245391 | 401 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 436 | |
| <input checked="" type="checkbox"/> NP_001297088 | 368 | DLIGCVCTLESFHYSDWL----QSSRRQSIPLSLSD 401 | |
| <input checked="" type="checkbox"/> NP_001297090 | 251 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 286 | |
| <input checked="" type="checkbox"/> NP_001297089 | 251 | GTSGTTSTGLISPGVSVPVQVPGSEPDMSQYWPRLO-- 286 | |

2015.05.23: I have now received a reply from the **GeneCard** folk concerning the discrepancy between the number of proteins and the number of transcripts. Clearly not a vital issue, except that this sort of thing should make the user wary when using these sorts of resources. As is universally true of all things human construction, they fall sadly short of perfect. I think ... they give me a slightly cloudy admission of "a bug" that will be fixed soon. Make you own mind up, but only if you feel so inclined, mostly for my benefit, I record their reply here:

"... **GeneCards** presents **RefSeq** based transcripts and proteins. In addition to transcripts and proteins, **RefSeq** has also predicted transcripts and predicted proteins ('**NM**' is for transcripts, while '**XM**' is for predicted transcripts. Similarly '**NP**' is for proteins while '**XP**' is for predicted proteins). The number of not predicted proteins matches the not predicted transcripts, same goes for the predicted items. In **GeneCards** current version we display the predicted transcripts, and do not display the predicted proteins, which causes the discrepancy you mention. **This issue will be fixed in a future version.**"

2015.07.08: Now a new version of **GeneCards**. No change as yet.

2015.08.31: Yet another new version of **GeneCards**. Still no change. Time for another moan?

2016.03.03: Further update to **Genecards**. No change. I give up.

How many transcripts are predicted by the Alternative Splicing Database (ASD)?

Well, it rather looks as if the **ASD** has come to the end, although its final release is still available from the **EBI**.

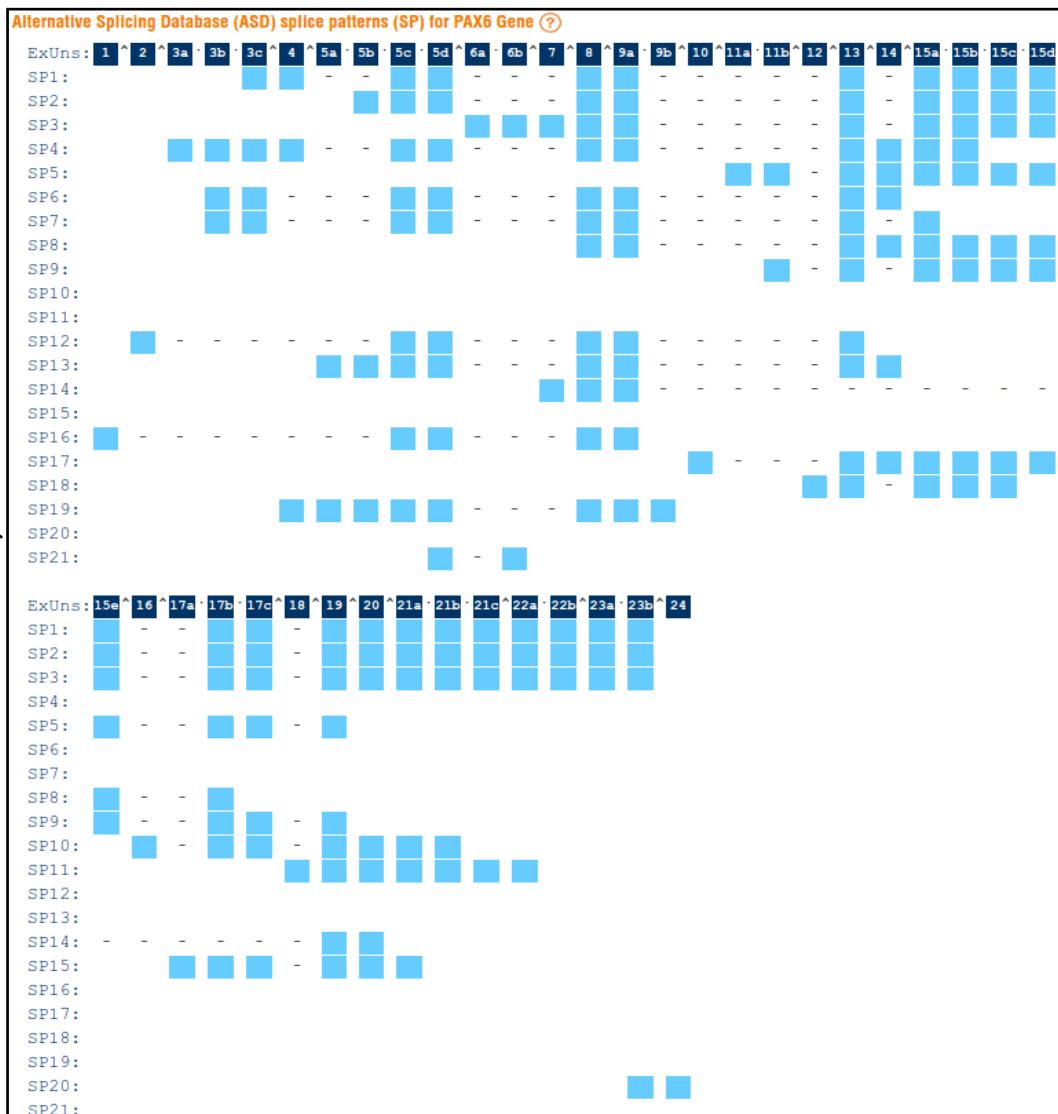
GeneCards claim they will be revising their policy to refer to **ASD** sometime in the future. They say:

"We currently do not have any links to **ASD**, as their data has been frozen and their site taken down. We plan to upgrade this subsection."

They also offer a brief explanation of how to interpret their graphic.

Genecards computes its graphic using information from both **ASD** and from a Korean resource (still active) called **Ecgene** (Genome Annotation for Alternative Splicing). So maybe this item will not entirely disappear?

As far as this discussion is concerned, **ASD** represents a resource that should be inclined to be quite generous about accepting the credibility



of possible splice variants. In contrast, before they started to admit less well evidence transcripts at least, one might expect **RefSeq** to be more fussy and therefore to predict less possibilities? Yes ... quite right ... if one includes the **RefSeq PREDICTED** mRNAs, this is no longer true.

Ignoring the dismal background, The raw observation remains that according to **ASD** there are 21 splice patterns for the **PAX6** gene.

How many transcripts are predicted by Ensembl?

(31) Ensembl transcripts including schematic representations, and UCSC links where relevant: ENST00000379132 ENST00000379129 ENST00000379107 ENST00000464174 ENST00000241001 ENST00000379115 ENST00000474783 ENST00000379111 (uc021qfn.1) ENST00000379123 ENST00000494377 ENST00000470027 ENST00000379109 ENST00000533333 ENST00000532916 ENST00000530373 ENST00000531910 ENST00000471303 ENST00000455099 ENST00000481563 ENST00000534390 ENST00000534353 ENST00000530714 ENST00000533156 ENST00000524853 ENST00000423822 ENST00000438681 ENST00000527769 ENST00000532175 ENST00000525535 ENST00000606377 ENST00000419022 (uc031pzk.1uc031pzl.1uc001mtd.4uc001mte.5uc001mtg.5uc001mtf.5uc001mth.5uc021qfl.1uc021qfm.1uc009yjr.3) See Less «

The **Ensembl** genome database predicts **31** transcripts for **PAX6**. The winner! True, but **Ensembl**, uniquely amongst the databases we have considered here, does not restrict itself to transcripts that are protein coding. Now that is simply cheating!

How would you rationalize the discrepancies?

The conflicting numbers of transcripts reported from assorted sources by **GeneCards** are all only predictions based on different evidence and with variant certainty criteria. The "real" number of transcripts is not known with certainty. Some single sources will predict different numbers of transcripts dependant upon credibility levels and evidence sources that can be set by the user. **Ensembl** is such a source, as you will see later.

It is also important to realise that the motivations of the various prediction source varies. The Alternative Splicing Database (**ASD**), for example set out to report transcripts that could occur given any reasonable splice variation, **RefSeq** transcripts (in principle at least) require a much more demanding level of evidence. **Ensembl** includes transcripts that are not protein coding, as you will soon see.

How many times does the term **PAX6** occur in this entry's annotation?

The term **PAX6** does not occur at all in the **Genbank** entry for **BX640762.1**¹⁴¹. Clearly, this will affect the way text searches involving the key **PAX6** work, as will be seen later.

The annotation of the entries of the early databases (**EMBL**, **GenBank**, **DDBJ**) was left to the submitter and so, rather haphazard. It would seem reasonable that this entry should mention the formal name of the gene it represents. We will touch on what is being done to improve this situation later..

Why might the number of Additional mRNA matches not match the number of **PAX6** transcripts?

(13) Additional mRNA sequences : AK094249.1 AB593094.1 AB593092.1 AB593093.1 AK074881.1 BX640762.1 AK314470.1 M93650.1 M77844.1 BC011953.1 AY047583.1 GQ141695.1 AY707088.1 See Less «

13 Additional mRNA sequences are recorded.

Genbank contains only entries that have been directly sequenced. If an **mRNA** was sequenced more than once it could be represented in **Genbank** more than once. If an **mRNA** exists that has never been sequenced directly, it will not be included in **GenBank**. So, there is no expectation that the **mRNAs** of a particular gene in **GenBank** should match any prediction of the number of transcripts there might be.

RefSeq attempts to represent the biological truth by including just one sequence for every predicted transcript. This often requires the inclusion of sequences that were not directly sequenced, but rather compiled from several directly generated sequences. **RefSeq** also attempts to remove redundancy where possible. So **RefSeq** should contain the same number of **mRNA** sequences as it supposes there to be transcripts.

¹⁴¹ As it would not in the corresponding **EMBL** or **DDBJ** entries as the annotation content in all three databases is identical (well nearly, there can be differences as you will discover later). Only the annotation format is supposed to differ between these databases.

What sort of variations are recorded in the Humsavar database?

Summary:

Humsavar entries record the presence of mutations in the protein. The position of the mutations are specified as amino acid positions relative to the canonical protein of the gene under investigation. Most of the Humsavar entries for PAX6 appear to be **Disease variants**.

Full Answer:

Humsavar is a simple text file providing an index of “**Human polymorphisms and disease mutations**”. It currently (2015.08.31) offers around **71,000** entries divided into three classifications.

| | | |
|-------------------------------|--------------|---|
| Disease variants: | 26874 | {Variants have been found in patients and disease-association is reported in literature. However, this classification is not a definitive assessment of variant pathogenicity.} |
| Polymorphisms: | 38105 | {No disease-association has been reported.} |
| Unclassified variants: | 6816 | {Variants have been found in patients but disease-association remains unclear.} |
| Total: | 71795 | |

This is in contrast to the **dbSNP** variations which refer to variations in the genomic whose position is specified as a number of base pairs from the start of the chromosome and are, generally, **NOT** disease related as it is not the prime purpose of **dbSNP** to record such variations (see later discussion).

Note that all **SNPs** available from **dbSNP** are also available from **Ensembl**. Why might that be?

Something of a trick question I fear. **Ensembl** regularly copies in all of the **dnSNP** database entries. Therefore, of course, all **dbSNP** entries will also be in **Ensembl**. I included this question as it does indicate an encouraging example of sharing data/information.

Why might it be considered odd that rs35883677 be included in dbSNP?

Summary:

Because this variation is not a **SNP** (Single Nucleotide Polymorphism). It is an **InDel** (Insertion/Deletion). It suggests that in the position indicated there is sometimes **no base** ("–") and sometimes there is an **A**. Sensibly, **dbSNP** is not mindlessly exclusive to **SNPs**. Other interesting variants are also recorded.

| Sequence variations from dbSNP and Humsavar for PAX6 Gene | | | | | | | |
|---|------|---------------|------------------|---------|-------------------------------------|--|-----|
| Filter: rs358 (Filtered 3 out of results) | | | | | | | |
| SNP ID | Clin | Chr 11 pos | Sequence Context | AA Info | Type | | MAF |
| rs35821697 ⁵⁴³ | -- | 31,797,364(+) | ACATT(C/T)TTATC | ? | intron-variant | | |
| rs35883677 ⁵⁴³ | -- | 31,794,440(+) | CACAC(-A)CACAC | ? | intron-variant | | |
| rs35840358 ⁵⁴³ | -- | 31,810,042(+) | AGAGC(C/G)CGGGG | ? | intron-variant, utr-variant-5-prime | | |

Full Answer:

In passing, rs35883677 is an **InDel**. But it is not labelled as such in the **Type** column? Not sure I understand why not. I have inquired.

2015.07.08: Searching specifically for **indels** seems to be something that might be very useful, but is rather inconsistent and illogical I think. If you filter in this region for “**indel**” at **GeneCards**, it tries to convince you there are only **2 indels** in this region. Nonsense! If one searches for “**-/-**” one gets **76** hits which I suggest are **indels**, but still not enough my intuition tells me. No clear answer from **GeneCards** help desk, they say “talk to **NCBI**” so I do. **NCBI** suggest a way to search their copy of the database which gives **216** hits for roughly the same region. Reasonable, but the search term is “**ind del**”? The space in the middle I would never have guessed. To be fair, it is possible to select the search term from a web site link, in which case you do not need to know about the whimsical space, which is essential if you use the **Advanced Search** in a similar fashion to the way you will experience in the exercise soon. They also offer an alternative way to search for **indels**:

“... Another route with a more graphical bent is to start in the Gene database record:

<http://www.ncbi.nlm.nih.gov/gene/5080>

Then go to the **Variation** section (**Table of Contents**), then to **See Variation Viewer (GRCh38)**. There are a lot of tracks you can remove in the **Configure** menu, and **Filters** on the left; one each for deletion and insertion. When I check **Source = dbSNP** and the **deletion** and **insertion** boxes, I end up with **107** variants.”

which seems quite logical to me, but generates yet another different number of hits? The possible explanation offered is:

“... I think the **dbSNP** page might include merged or removed records ...”

which sounds quite likely, if a trifle depressingly unpredictable.

Ensembl call **indels Insertions or Deletions** (as far as I can tell), but I can see no way to search for them using **Biomart**. I continue to investigate.

2015.07.09: I suspect the problem with search for **indels** in **GeneCards** is that they have mislabelled the **Molecular consequence dbSNP** field as the **Variation Type** field. This will not work surely? A variation of type **Insertion** could easily have a **molecular consequence** that does not involve the word **Insertion** (or **Deletion**, or **indel**, or “**in del**”). I have asked for elucidation.

2015.08.31: Nothing so far, asked again. Pretty certain my theory is correct.

2016.03.04: Still nothing. OK chaps, I give up. So we just live with these inconsistencies I suppose.

The Ensembl Accession Number for the **aniridia** gene.

The **Ensembl** accession code for **PAX6** is:
ENSG00000007372

External Ids for PAX6 Gene

HGNC: 8620 Entrez Gene: 5080 Ensembl: ENSG00000007372 OMIM: 607108 UniProtKB: P26367

Not a vital piece of information at for now, but you will meet this **Accession Number** several times in the next few pages, so I thought I would get the formal introductions over early.

Note the outrage of leading zeroes before the quite modest number that really identifies the gene. It will be a good idea to remember that there are **7** of them at this stage. It makes my eyes hurt and the rest of me weary to count them every time I type them in.

This **Accession Number** was designed in the days when the deep thinkers were estimating many many more genes than there actually turned out to be. They did not manage to think deeply enough to predict that splice variation would provide such variety as it does. With one gene capable of producing many variant protein forms, significantly fewer genes are required.

The trouble is that once one has designed a field capable of representing a very very big number, it is not trivial/practical to redesign it when one realizes that said field is a good four zeroes over provided. So we live with lots of leading zeroes with nothing much to do. Quite amusing really. In a perverse sort of way.

The number of human **PAX** genes.

Paralogs for PAX6 Gene

PAX4⁵ PAX8⁵ PAX5⁵ PAX2⁵ PAX9⁵ PAX7⁵ PAX1⁵ PAX3⁵

According to **GeneCards** **PAX6** is one of **9** human **paralogues**. This information **Genecards** copies from **Ensembl**. As before, you could follow the **5** superscript links to see the **Ensembl** view of each parologue.

What Orthologues exist in Mouse and Drosophila?

Summary:

| Orthologs for PAX6 Gene <small>(?)</small> | | | | | | See less « |
|--|----------|--------------------|------------------------|----------|--------------------------------------|------------|
| Organism | Taxonomy | Gene | Similarity | Type | Details | |
| cow
(Bos Taurus) | Mammalia | PAX6 ³⁵ | 97 (n)
99.76 (a) | | 286857 NM_001040645.1 NP_001035735.1 | |
| | | PAX6 ³⁶ | 100 (a) | OneToOne | 15:63356631-63384294 | |
| mouse
(Mus musculus) | Mammalia | Pax6 ³⁵ | 94.34 (n)
99.77 (a) | | 18508 NM_001244198.1 NP_001231127.1 | |
| | | Pax6 ¹⁶ | | | 105668900 | |
| | | Pax6 ³⁶ | 100 (a) | OneToOne | 2:105668900-105697364 | |
| chimpanzee
(Pan troglodytes) | Mammalia | PAX6 ³⁵ | 99.15 (n)
99.49 (a) | | 737387 XM_003954364.1 XP_003954413.1 | |
| | | PAX6 ³⁶ | 99 (a) | OneToOne | 11:31718289-31729470 | |

Ask to See all the orthologues listed, the default list is rather withered!

In **Mouse**, as in a number of other organisms, the orthologous gene has the same name as in **Human (PAX6)**.

| | | | | | | |
|--|---------|--------------------|------------------------|------------|-------------------------------|--|
| fruit fly
(Drosophila melanogaster) | Insecta | ey ³⁷ | 93 (a) | | | |
| | | Poxn ³⁷ | 64 (a) | | | |
| | | sv ³⁷ | 73 (a) | | | |
| | | toy ³⁷ | 50 (a) | | | |
| | | toy ³⁵ | 58.48 (n)
65.94 (a) | | 43833 NM_079899.4 NP_524638.3 | |
| | | ey ³⁶ | 30 (a) | ManyToMany | 4:718315-741787 | |
| | | toy ³⁶ | 48 (a) | ManyToMany | 4:1010351-1028548 | |

In **Drosophila** there are several orthologues. **ey** (eyeless) and **toy** (twin of eyeless) being the most important. The naming of the **Drosophila** genes is a little more whimsical than elsewhere.

Full Answer:

Drosophila is an important model organism for the study of **Aniridia**. You will see later another **Drosophila** gene mentioned as an important **orthologue** of **PAX6** in human. The orthologue not mentioned here is **prd** (paired) and it is indeed a genuine **orthologue**. I am not entirely clear why it does not appear here (despite several explanations from experts). Here is the nearest I got (from the Flybase team) to an answer, sort of:

“As you know, there is often a one-to-many relationship with these things. **prd** is considered (according to **OrthoDB**, which **FlyBase** uses) to be orthologous to **Pax1**, **Pax2**, **Pax3**, **Pax4**, **Pax5**, **Pax6**, **Pax7**, **Pax8**, and **Pax9**. More info here: <http://flybase.org/reports/FBgn0003145.html> in the **Orthologs -> Human orthologs** section.

More info on how we calculate these relationships can be found [here](#).

I have no idea what **Ensembl** are doing. They are often slightly out of sync with some aspects of our data.

ey and **toy** are related, and are also both orthologous to **Pax1, 2, 3, 4, 5, 6, 7, 8, and 9**.

So, on the basis of sequence relationship, **ey**, **toy**, and **prd** are **PaxX** orthologues.”

This seems to say that the **FlyBase** chaps think the **Ensembl** fellows have missed something?

One could continue to speculate on the mention here of the **Poxn** gene, or the **sv** gene, but I do not feel sufficiently bold.

What functions are suggested for PAX6?

In the Summary section:

[UniProtKB/Swiss-Prot for PAX6 Gene](#) PAX6_HUMAN_P26367

Transcription factor with important functions in the development of the eye, nose, central nervous system and pancreas. Required for the differentiation of pancreatic islet alpha cells (By similarity). Competes with PAX4 in binding to a common element in the glucagon, insulin and somatostatin promoters. Regulates specification of the ventral neuron subtypes by establishing the correct progenitor domains (By similarity). Isoform 5a appears to function as a molecular switch that specifies target genes.

[Gene Wiki entry for PAX6 Gene](#)

More general information is available from the [Gene Wiki entry for PAX6 Gene](#). Here it claims, with confidence, there to be just four **Drosophila** orthologues for **PAX6**.

“Of the four **Drosophila Pax6** orthologues, it is thought that the **eyeless (ey)** and **twin of eyeless (toy)** gene products share functional homology with the vertebrate canonical **Pax6** isoform, while the **eyegone (eyg)** and **twin of eyegone (toe)** gene products share functional homology with the vertebrate **Pax6(5a)** isoform. **Eyeless** and **eyegone** were named for their respective mutant phenotypes.”

No mention here of **prd**, **sv** or **Poxn**, plus we meet **toe** and **eyg** for the first time? It is time to remind ourselves that the discovery of details about the example gene **PAX6** is **NOT THE POINT** here! It is, however, valuable to see just how far from a clear, stable and singular picture is available from the various resources visited. I suspect this will not surprise many of you. After all, we are mostly sifting amongst predictions, as opposed to concrete facts. What we find is laced with opinion and differing interpretation. Life is not straight forward. I am never quite sure whether that is a good thing or a bad thing, but it certainly can be frustrating at times.

[Entrez Gene Summary for PAX6 Gene](#)

This gene encodes a homeobox and paired domain-containing protein that binds DNA and functions as a regulator of transcription. Activity of this protein is key in the development of neural tissues, particularly the eye. This gene is regulated by multiple enhancers located up to hundreds of kilobases distant from this locus. Mutations in this gene or in the enhancer regions can cause ocular disorders such as aniridia and Peter's anomaly. Use of alternate promoters and alternative splicing result in multiple transcript variants encoding different isoforms. [provided by RefSeq, Jul 2015]

The information from **Entrez** offers a better description of the expected domains.

It notes that mutations in the gene can result in **Aniridia** and similar disorders. **Entrez** also mentions multiple isoforms, as suggested elsewhere.

[GeneCards Summary for PAX6 Gene](#)

PAX6 (Paired Box 6) is a Protein Coding gene. Diseases associated with PAX6 include [aniridia](#) and [peters anomaly](#). Among its related pathways are [Developmental Biology](#) and [Regulation of beta-cell development](#). GO annotations related to this gene include *transcription factor activity, sequence-specific DNA binding* and *chromatin binding*. An important paralog of this gene is **PAX3**.

GeneCards has, relatively recently, offered its own version! It seems a bit sparse, but maybe there will be more later.

Uniquely, this descriptions mentions pathways and annotation based on **Gene Ontology (GO)**, discussed later associations. The **GeneCards Summary** only refers to **one** of the **eight** paralogues? Maybe **PAX4** is more important than the others?

I found I had to read all the descriptions several times before I could see that they were all roughly agreeing. Different views of the same topic? There are many ways of looking at anything after all.

In the Function section:

[Molecular function for PAX6 Gene](#)

GENATLAS Biochemistry: paired box (DNA binding) containing protein 6, with homeo domain, expressed in the central nervous system and endocrine pancreas, key regulator of eye development and regulator of glial precursors in the ventral neural tube. **PAX6**
UniProtKB/Swiss-Prot Function: Transcription factor with important functions in the development of the eye, nose, central nervous system and pancreas. Required for the differentiation of pancreatic islet alpha cells (By similarity). Competes with PAX4 in binding to a common element in the glucagon, insulin and somatostatin promoters. Regulates specification of the ventral neuron subtypes by establishing the correct progenitor domains (By similarity). Isoform 5a appears to function as a molecular switch that specifies target genes. PAX6_HUMAN_P26367

GeneCards refers to **GENATLAS** and **UniProtKB** for information about function.

The contribution from **UniProtKB** is identical to that quoted in the **Summary** section. **GENATLAS**, another human gene database, finds a different way to say similar things.

[Gene Ontology \(GO\) - Molecular Function for PAX6 Gene](#)

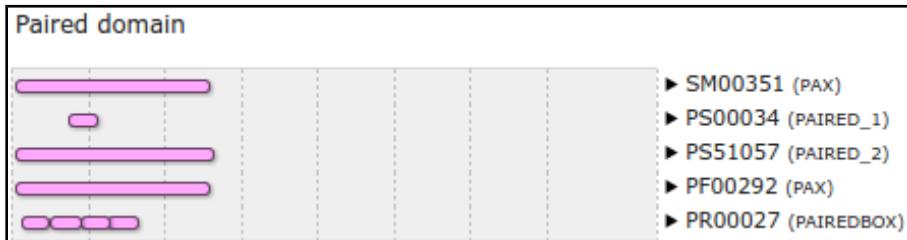
| Filter: | (results) | See all 20 » | |
|------------|---|--------------|------------|
| GO ID | Qualified GO term | Evidence | PubMed IDs |
| GO:0000978 | RNA polymerase II core promoter proximal region sequence-specific DNA binding | null | |
| GO:0000979 | RNA polymerase II core promoter sequence-specific DNA binding | IDA | 20592023 |
| GO:0000981 | RNA polymerase II transcription factor activity, sequence-specific DNA binding | IDA | 20592023 |
| GO:0001077 | transcriptional activator activity, RNA polymerase II core promoter proximal region sequence-specific binding | null | |
| GO:0001227 | transcriptional repressor activity, RNA polymerase II transcription regulatory region sequence-specific binding | null | |

GeneCards also lists all the **Gene Ontology** terms associated with the molecular function of **PAX6**. If you look at all 22, they seem mostly consistent with that which we have discovered thus far.

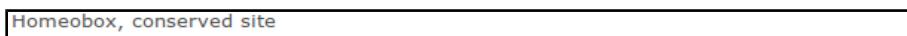
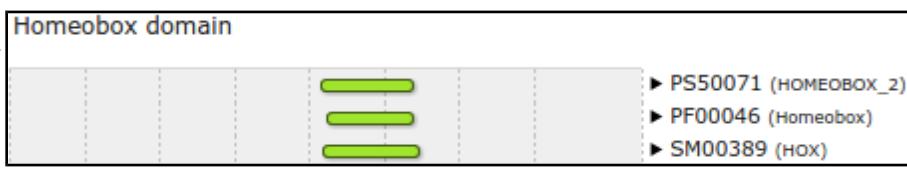
Why there are two Prosite predictions for both the Homeobox and the Paired Box domains?

All **Prosite** accession codes begin **PS**. For most domains, **Prosite** includes a **Hidden Markov Model (HMM)** entry representing the entire domain and a simple **Pattern** entry representing a smaller highly conserved signature within the domain. In most instances, a single protein domain will match both a **Prosite HMM** and a **Prosite Pattern** entry giving the initial impression that there might be two domains, a large one with a smaller one contained within it.

In this example, **PS51057** is the **HMM** representing the conservation apparent over the entirety of most **Paired Box** domains. **PS00034** is the **Pattern** representing the extremely high conservation evident over a very small (17 amino acids) region of most **Paired Box** domains.



PS50071 is the **HMM** representing the conservation apparent over the entirety of most **Homeobox** domains. **PS00027** is the **Pattern** representing the extremely high conservation evident over a significantly smaller region of most **Homeobox** domains. The **Pattern** in this case is not considered strong enough to be taken too seriously. It is demoted to a “**conserved site**” and appears in a separate graphic.



Why **Prints** appears to predict four very small **Paired box** domains instead of the single larger domain indicated by all the other predictions?

All **Prints** accession codes begin **PR**. **Prints** entries do not normally represent domains as a single conserved feature. Instead they define a number of features (each of which may not be significant considered in isolation) that must all occur in a given order and within a specified distance of each other. Matches with each element of a **Prints** entry are represented separately, so a single domain detected by a match with a **Prints** entry can erroneously appear to be a match with a series of very small domains.

In this example, the **Prints** entry for a **Paired Box** domain is **PR00027**. For **Prints** to recognize a **Paired Box** domain, 4 relatively small conserved signatures must be found in a specific order. Each of the 4 matches is represented separately although **Prints** is only claiming to have discovered a single **Paired Box** domain.



From your investigations using OMIM:

What do you notice about all the variants that are associated with a **dbSNP** entry?

They are all substitutions rather than **insertions** or **deletions (indels)**. At first glance, this would seem logical as, if accurately named, the **dbSNP** database really should contain only **Single Nucleotide Polymorphisms (SNPs**, i.e. substitutions). However, there are lots of **indels** recorded in the **dbSNP** database, so maybe the observation here is just chance or reflects only that the majority of **dbSNP** database entries are substitutions? Maybe this was not such a good question to ask after all.

Does this surprise you?

I am no longer sure. Maybe it surprises me more than it used to? Maybe many things surprise me more than they used to?

From your investigations using Entrez:

What were the features that you found?

Summary:

The first feature was the **CoDing Sequence (CDS)** for a **PAX6** isoform.

The other three features were the coding sequences for three **ELP4** isoforms.

| | | |
|---|--|---|
| <pre>complement(39424..>39569) /gene="ELP4" /gene_synonym="AN; C1orf19; DJ68P15A.1; hELP4; PAX6NEB; PAXNEB" /inference="similar to AA sequence (same species):RefSeq:NP_001275654.1" /exception="annotated by transcript or proteomic data" /note="isoform 2 is encoded by transcript variant 2; elongator complex protein 4; PAX6 neighbor gene protein; elongation protein 4 homolog" /codon_start=3 /product="elongator complex protein 4 isoform 2" /protein_id="NP_001275654.1" /db_xref="GI:570359562" /db_xref="GeneID: 26610 " /db_xref="HGNC: 1171 " /db_xref="MIM: 606985 " /translation="MAAVATCGVAASTGSAVATASKSNVTFSQRRGRPRAVSNTDGP RLVSIAGTRPSVRNGQLLVSTGLPALDQLLGGGLAVGTVLLEEDKYNIYSPLLFKYF LAEGIVNGHTLLVASAKEDPANILQELPAPLDDKKKEFDDEVNHKTPESNIKMKI AWRYQLPKMEIQLGVPSSRFGHYYDASKRMPQELIASNHGFFLPKISSTLKVEPC CSLTPGYTQLLQFIQNIIYEFGDGSNPQKKQRNLIIRGIQNLGSPWGDICCAENG NSHSLTKFLYVLRGLLRTSLSACITMPTHLIQNKAIARVTTLSVDVVVGLESFIGSE ERETNPLYKDYHGLIHIRQIPRNLNLCODESDVKDLAFKLKRKLFTIERHLPPDLSDT RNIPPPGSYLLKQKDSAWGEGLQHSTFLMSFLAKATAFASRVRHSEPLKQNGSGR IRQAQPLRWHIDGRPQAPGLLLQIPP"</pre> | <pre>complement(39438..>39569) /gene="ELP4" /gene_synonym="AN; C1orf19; DJ68P15A.1; hELP4; PAX6NEB; PAXNEB" /inference="similar to AA sequence (same species):RefSeq:NP_061913.3" /exception="annotated by transcript or proteomic data" /note="isoform 1 is encoded by transcript variant 1; elongator complex protein 4; PAX6 neighbor gene protein; elongation protein 4 homolog" /codon_start=1 /product="elongator complex protein 4 isoform 1" /protein_id="NP_061913.3" /db_xref="GI:91208435" /db_xref="CCDS: CDS7875.2" /db_xref="GeneID: 26610 " /db_xref="HGNC: 1171 " /db_xref="MIM: 606985 " /translation="MAAVATCGVAASTGSAVATASKSNVTFSQRRGRPRAVSNTDGP RLVSIAGTRPSVRNGQLLVSTGLPALDQLLGGGLAVGTVLLEEDKYNIYSPLLFKYF LAEGIVNGHTLLVASAKEDPANILQELPAPLDDKKKEFDDEVNHKTPESNIKMKI AWRYQLPKMEIQLGVPSSRFGHYYDASKRMPQELIASNHGFFLPKISSTLKVEPC SLTPGYTQLLQFIQNIIYEFGDGSNPQKKQRNLIIRGIQNLGSPWGDICCAENG NSHSLTKFLYVLRGLLRTSLSACITMPTHLIQNKAIARVTTLSVDVVVGLESFIGSE RETNPPLYKDYHGLIHIRQIPRNLNLCODESDVKDLAFKLKRKLFTIERHLPPDLSDT VSRSKMDLAESAKRLGPQCGMMAGKKKHDF"</pre> | <pre>complement(39533..>39569) /gene="ELP4" /gene_synonym="AN; C1orf19; DJ68P15A.1; hELP4; PAX6NEB; PAXNEB" /inference="similar to AA sequence (same species):RefSeq:NP_001275655.1" /exception="annotated by transcript or proteomic data" /note="isoform 3 is encoded by transcript variant 3; elongator complex protein 4; PAX6 neighbor gene protein; elongation protein 4 homolog" /codon_start=2 /product="elongator complex protein 4 isoform 3" /protein_id="NP_001275655.1" /db_xref="GI:570359564" /db_xref="GeneID: 26610 " /db_xref="HGNC: 1171 " /db_xref="MIM: 606985 " /translation="MAAVATCGVAASTGSAVATASKSNVTFSQRRGRPRAVSNTDGP RLVSIAGTRPSVRNGQLLVSTGLPALDQLLGGGLAVGTVLLEEDKYNIYSPLLFKYF LAEGIVNGHTLLVASAKEDPANILQELPAPLDDKKKEFDDEVNHKTPESNIKMKI AWRYQLPKMEIQLGVPSSRFGHYYDASKRMPQELIASNHGFFLPKISSTLKVEPC SLTPGYTQLLQFIQNIIYEFGDGSNPQKKQRNLIIRGIQNLGSPWGDICCAENG NSHSLTKFLYVLRGLLRTSLSACITMPTHLIQNKAIARVTTLSVDVVVGLESFIGSE RETNPPLYKDYHGLIHIRQIPRNLNLCODESDVKDLAFKLKRKLFTIERHLPPDLSDT ASQSAGITGSSNPASLASVAGITGAHHHTQLIFVFLVEMGFHVHQAGLELLTSGDSSAS RFFTAHFIFNELPCKGDCICLQTCQTQ"</pre> |
|---|--|---|

Full Answer:

Note that only the final coding exon of **ELP4** is within this **RefSeq** sequence, which is defined as the genomic region for **PAX6**. This is clear from the length of the **translations** offered. The exon referenced is only long enough to code for just over **40** amino acids which is far short of any of the three isoform sequences offered here.

Note also that this final coding exon of **ELP4** (stretching from **39438** to **39569** of this **RefSeq** entry) does **not** overlap the coding region of the **PAX6** gene itself (stretching from **16551** to **33028** of this **RefSeq** entry)¹⁴².

In fact, the two entire genes do not overlap according to the evidence here. The entire **PAX6** gene extends from **5001** to **38170**. The portion of the **ELP4** gene that is included in this entry extends from **40170** (the end) to **38437** (in the opposite direction). This give a gap between the two genes stretching from **38171** to **38436**.

| | |
|--|---|
| <pre>gene 5001..38170 /gene="PAX6" /gene_synonym="AN; AN2; D11S812E; MGDA; WAGR" /note="paired box 6" /db_xref="GeneID: 5080" /db_xref="HGNC: 8620" /db_xref="MIM: 607108"</pre> | <pre>gene complement(38437..>40170) /gene="ELP4" /gene_synonym="AN; C1orf19; DJ68P15A.1; hELP4; PAX6NEB; PAXNEB" /note="elongator acetyltransferase complex subunit 4" /db_xref="GeneID: 26610" /db_xref="HGNC: 1171" /db_xref="MIM: 606985"</pre> |
|--|---|

As you will see later, **Ensembl** will confirm the lack of overlap between these two genes graphically as well as their relative positions.

Note that **ELP4** was associated with **aniridia** by **GeneCards**. However, I believe only because of its proximity to **PAX6**.

142 The features here only represent the **CDS** regions of the genes. I wonder why not the entire transcript length?

Why might you have expected more features than there were?

Summary:

GeneCards (referring to UniProt) suggested that **PAX6** has three isoforms. This would lead me to expect three features here related to **PAX6**?

Full Answer:

As you will discover later, one of the **PAX6** isoforms could not be represented in the fashion displayed here, but I would still expect there to be two **PAX6** isoform features. The explanation from the NCBI is that this sort of RefSeq entry is intended to be used as a template against which sequences from an individual can be mapped to seek variations. Only a token CDS feature is included to indicate the position of the gene. For such an entry, recording every isoform is not essential.

This sounded convincing to me. Until I began to wonder why there were three CDS features for **ELP4** which is not even the gene primarily represented by this entry? Maybe I will ask more questions if and when I ever have the strength. In the meantime, mostly for my information, I record their exact explanation here.

“ ... note that **RefSeqGene** defines genomic sequences to be used as reference standards for well-characterized genes. These sequences serve as a stable foundation for reporting mutations, for numbering exons and introns, and for defining the coordinates of other variations. We normally select one **RefSeq** transcript to serve as a reference standard. The goal is not to record all introns and exons of all isoforms, but just to choose one representative to help define the locus. Therefore, most of our **RSG** records have only a single **RefSeq** as reference standard. If an **LSDB** manager or other stakeholder requests that other **RefSeqs** be added as alternate standards, this can easily be done (with the complication that, if a public **LRG** exists, the **RefSeqGene** record is fixed). We receive requests from stakeholders to include **RefSeqs** that represent all known exons, or **RefSeqs** that have become community standards. Often, after creating an **RSG** using our own internal criteria, we receive stakeholder requests to change or add transcripts. Many of these requests come from the **LRG** project regarding transcripts to be included on the **LRG** records.

Generally, **RefSeq** accessions can be added or removed without reversioning, unless a transcript is upgraded or a new one defined that extends beyond the bounds of the **RSG**, or matches a new build of the genome, in which case the **RSG** will be extended and reversioned as needed.

Regarding the chromosomal locus, our standard range is 5 kb upstream from the 5' end and 2 kb downstream from the 3' end of the mRNAs with the greatest extent. For this calculation, we do indeed use all available **RefSeq (NM_)** accessions. If the database manager or stakeholder has information on promoters or other upstream or downstream regulatory regions, we can certainly extend the **RefSeqGene** locus to accommodate these.

Regarding mismatches, the goal is to exactly match the current build of the genome, unless there is overwhelming transcript and EST evidence that a mismatch should be retained.

Regarding the confusing subject of exon numbering, exon numbers are currently provided only on **RSG** genomic records based on a subset of available transcript **RefSeqs** for the gene. These are often those selected by locus-specific databases as reference sequence reporting standards. You can find an explanation of how exons are numbered here:

<http://www.ncbi.nlm.nih.gov/refseq/rsg/faq/#exon>

You will find links to more information on **RefSeqGenes** on the home page for the **RefSeqGene** project:-

<http://www.ncbi.nlm.nih.gov/refseq/rsg/>

Regarding the **PAX6 RSG** sequence, only difference I see between **NG_008679.1** and the current build of the genome (**GRCh38**) is an extra 'G' beyond the 3'-UTR of the **PAX6** transcripts (at **NC_000011.10:g.31,819,125**). ... “

Yes, well I think I followed most of that? and that my interpretation is broadly correct? In summary, there are no fixed rules.

How does the alignment you generated match up with the annotation of the original RefSeq entry you discovered?

Summary:

The most intuitive way of encapsulating graphically the way these two sequencing clones overlap was donated by **Cecilia Pinto (Oeiras, 2013.12.09-12)**. Much better than my rambling attempts, that I keep for sentimental reasons in the “Full Answer”. Thank you Cecilia.

Z95332 (1 - 20 874) Contig.

1 - 2 022

2 023 - 20 770

20 771 - 20 874

NG_008679 (1 - 40 170) pax6

1 - 104

105 - 21422

21 423 - 22253

Z83307 (1 - 22 253) Contig.

Full Answer:

Do not spend too much time working this one out, the picture above should be more than sufficient. I just needed to see it all balanced ... then I can sleep soundly?

If you do want to read on, I strongly suggest you look at the picture contributed by Cecilia (now promoted to the “**Summary Answer**”) first. So simple! I have to admit I cannot follow my own wonderful table at all now ... at least, not without bleeding! Although, it did feel good at the time?

| | |
|--------------------------|---|
| <input type="checkbox"/> | Human DNA sequence from clone CFAT5 on chromosome 11, complete sequence |
| 1. | 20,874 bp linear DNA
Accession: Z95332.1 GI: 2190397
GenBank FASTA Graphics |
| <input type="checkbox"/> | Human DNA sequence from clone A1280 on chromosome 11, complete sequence |
| 2. | 22,253 bp linear DNA
Accession: Z83307.1 GI: 1730464
GenBank FASTA Graphics |

So ...

| | | |
|-------------|---|-------|
| Query 20771 | GATCCGGAGCGACTTCCGCTATTCCAGAAATTAGCTCAAACTTGACGTGCAGCTAGT | 20830 |
| Sbjct 1 | GATCCGGAGCGACTTCCGCTATTCCAGAAATTAGCTCAAACTTGACGTGCAGCTAGT | 60 |
| Query 20831 | TTTATTTAAAGACAAATGTCAGAGGGCTCATCATATTTC | 20874 |
| Sbjct 61 | TTTATTTAAAGACAAATGTCAGAGGGCTCATCATATTTC | 104 |

The Query sequence is **Z95332 (Length 20,874)**

The Subject sequence is **Z83307 (Length 22,253)**

| PRIMARY | REFSEQ_SPAN | PRIMARY_IDENTIFIER | PRIMARY_SPAN | COMP |
|-------------|-------------|--------------------|--------------|------|
| 1-18852 | Z95332.1 | | 2023-20874 | |
| 18853-40170 | Z83307.1 | | 105-21422 | |

| NG_008679 Range Start | NG_008679 Range End | NG_008679 Range | Z95332 Range Start | Z95332 Range Start | Z95332 Range | Z83307 Range Start | Z83307 Range End | Z83307 Range |
|-----------------------|---------------------|-----------------|--------------------|--------------------|--------------|--------------------|------------------|--------------|
| - | - | - | 1 | 2022 | 2022 | - | - | - |
| 1 | 18748 | 18748 | 2023 | 20770 | 18748 | - | - | - |
| 18749 | 18852 | 104 | 20771 | 20874 (end) | 104 | 1 | 104 | 104 |
| 18853 | 40170 (end) | 21319 | - | - | - | 105 | 21422 | 21318 |
| - | - | - | - | - | - | 21423 | 22253 (end) | 831 |
| | | 40171 | | | 20874 | | | 22253 |

Legend:

Not used in construction of RefSeq entry NG_008679

Non-overlapping GenBank entry used in construction of RefSeq entry NG_008679

Overlapping GenBank entry used in construction of RefSeq entry NG_008679

Total entry lengths

The RefSeq entry was thus constructed by overlapping the two Genbank entries and then manually trimming away the edges to form a biologically meaningful region. If I was a bit brighter, I think I might have come to that conclusion without the fuss above? Oh well, one has to use what one has.

I refer you again to the far more intuitive way of encapsulating the same message graphically, donated by **Cecilia Pinto** that is now the “**Summary Answer**” above. Much better! Thank you Cecilia.

From your investigations using UniProtKB:

Where have you seen these genes mentioned previously?

PAX6 and **ELP4** were the genes mentioned in the annotation of the RefSeq entry **NG_008679**. Part of both of these genes are contained in the clone you are looking at here, **Z83307**.

How is that this is the first occasion that the gene **RCN1** has been apparent?

To avoid mention up to this point, the **RNC1** gene must be entirely in the portion of the sequencing clone **Z95332** that does not include any part of the sequencing clone **Z83307**. That is, between bases **1 and 20770** of **Z95332** (see illustrations from a few answers back).

When we look at the location views in **Ensembl**, you will see clearly how the three genes **PAX6**, **ELP4** and **RNC1** share the same region of **Chromosome 11** and how they overlap the **2** sequencing clones. You will also be able to easily identify the genes and investigate them in precisely the manner we are investigating **PAX6**, should the urge fall upon you.

How is it that we have found any protein sequences at all by looking at the barren annotation of the two clones **Z83307** and **Z95332**?

The only way that the **UniProtKB** search facility can find proteins from the sequencing clone accession numbers you supplied, is to follow information it finds in the annotation of those clones. But ... there was no such information! At least, not when you looked at these clones (**Z83307** and **Z95332**) at the NCBI.

This search references the same clones stored in **EMBL-Bank**. The annotations of **GenBank** and **EMBL-Bank** are not identical. The main content, established by the International Nucleotide Sequence Database Collaboration (INSDC), will be the same in all but format. However, the **NCBI (GenBank)** and the **EBI (EMBL-Bank)**, will occasionally, whimsically add content to ensure that life remains distant from any user aspiration for consistency.

In this instance, the **EMBL-Bank** versions of the clones, **Z83307** and **Z95332**, include links to genes and transcripts determined by **Ensembl** plus links to other databases including **UniprotKB** and **Interpro**. It is these extra Database Cross-Reference (DR) lines that are being used to identify the **UniProtKB** entries.

Note that the annotation does not relate the genes and transcripts to which it refers to any particular regions of the genomic DNA? For this we must wait until we investigate **Ensembl**.

In readiness of that heady experience, I note that the **Ensembl** codes for the three genes are:

ENSG0000007372 - which is **PAX6**, of course, and noted in both clones.

ENSG00000109911 - which is **ELP4**, the second gene mentioned in the clone **Z83307**

ENSG00000049449 - which is **RCN1**, the second gene mentioned, but only in the clone **Z95332**

Note that there is, of course, no mention of **ENSG00000049449** in the illustrated annotation of **Z83307**.

Make a note of the first **UniProtKB Accession number** for the **PAX6** protein.

The first (**Primary**) **PAX6** protein accession code is **P26367**

Not a challenging question, just a hint that this code will occur regularly as the pages drift by.

Why do you suppose there is more than one **Accession number** for this protein?

The **PAX6** protein has three accession codes in total. **P26367**, **Q6N006** and **Q99413**.

Before publication, a protein sequence must be allocated a **UniProtKB** accession number. Every **UniProtKB** entry has an accession number. As **UniProtKB** evolves, entries are merged to save space. For example, it might be considered sensible to merge two very similar variants of a single protein (**isoforms**) and to record their differences as a **Variation Sequence (VAR_SEQ) Feature Table (FT)** entry. Each merge event creates a redundant accession code. However, accession codes must not be lost. It must always be possible to find a sequence using the accession code allocated when originally published. To make this possible, accession codes made “redundant” by entry merges are retained as **Secondary** accession codes. The accession code thought to be most important is kept as the **Primary** accession code.

In this case, **P26367** is the **Primary** accession code. **Q6N006** and **Q99413** are **Secondary accession codes**. Searching **UniProtKB** for any of these three **accession codes** will work.

There is even a **Complete history** button for those wishing for more detail.

| | | |
|--|---------------------------------------|----------------|
| Entry history ¹ | Integrated into UniProtKB/Swiss-Prot: | August 1, 1992 |
| | Last sequence update: | July 15, 1999 |
| | Last modified: | July 22, 2015 |
| This is version 185 of the entry and version 2 of the sequence. [Complete history] | | |

Make a note of the **UniProtKB Identifier** (or entry name).

The **UniProtKB Entry name** of the **PAX6** protein is **PAX6_HUMAN**. Unlike sequences in the DNA databases, a sequence in **UniProtKB** can have two names, an **Entry name** and an **Accession Code**.

Again, not a question to challenge, just a hint that this **Identifier** will occur regularly it that which follows.

What are the start and end positions of the **Paired** domain?

These next three “questions” are really not attempting to query, but to get you to just be aware of the values I have included in the text. Hopefully, you will see why later. No real need to write them down again, but ... just in the name of pedantry:

UniProtKB claims the **Paired** domain of the **PAX6** Human protein extends from residues **4 → 130**.

What are the start and end positions of the **Homeobox** domain?

UniProtKB claims the **Homeobox** domain of the **PAX6** Human protein extends from residues **210 → 269**.

Note the range of the **Proline, Serine, Threonine** rich region at the end of the protein.

UniProtKB claims the **Proline, Serine, Threonine** compositionally biased region of the **PAX6** Human protein extends from residues **279 → 422**. This region will be detected by software you use later and its properties given due regard.

Why do you suppose this is the case?

The Single Nucleotide Polymorphism database (**dbSNP**) database has entries for a variety of classes of polymorphisms, from a variety of organisms. As ever, **Wikipedia** provides a pleasingly simple description.

There seems to be no hard and fast rules about which variations are to be included, however, reading from various sources, the main focus is on variations for which the Minor Allele Frequency (**MAF**) is \geq than 1%¹⁴³. **Wikipedia** suggests the purpose of the database to be:

“physical mapping, **population genetics**, investigations into evolutionary relationships, as well as being able to quickly and easily quantify the amount of variation at a given site of interest. In addition, **dbSNP** guides applied research in **pharmacogenomics** and the association of genetic variation with phenotypic traits.”

I read this to mean primarily population studies and similar, where variations that do not cause major problems but are present at significant levels are the major interest.

Specifically concerning disease causing variations, from the **NCBI** pages I find:

“Originally, the great majority of data in **dbSNP** was collected and defined as variations simply using sets of co-aligned genomic or DNA sequences. Because this process typically had little to no focus on disease condition, only about **250** records in **dbSNP** were successfully associated with phenotype-causing variations or a clinical outcome in **OMIM**.

Starting in the Spring of 2008, however, **dbSNP** began accepting submissions of **Clinical/LSDB** variations as well as annotations to existing variations (including phenotype) ... Currently there are a total of **1266** records in **dbSNP** that were submitted as **Clinical/LSDB** variations ... and **1134** records submitted as **Clinical/LSDB** variations that also have **OMIM** links ...”

I read this to mean there might well be a far greater focus on disease causing variations in the future, but for now, they will be sparse. This is, I submit, what we see evidenced here.

In passing, I regard the patchy evidence provided here for that which I believed in the first place as unsatisfactory. If anyone can suggest anything better, I would be ever so grateful.

Describe the arrangement of Helices within **PAX6**.

From the evidence of the textual table and the graphics, both included in the text above, there are clearly **nine** helices in all that occur in groups of **three**.

Note the start position of the middle helix of each set of three.

I have deliberately included this information in the text. Again, this is not really a “question” but an invitation to notice something. No real need to write anything, but there again ... why not:

| | |
|--|------------|
| According to UniProtKB , the second helix of the first triplet starts at residue | 39 |
| According to UniProtKB , the second helix of the second triplet starts at residue | 99 |
| According to UniProtKB , the second helix of the third triplet starts at residue | 237 |

Note the end position of the third helix of each set of three.

| | |
|--|------------|
| According to UniProtKB , the first helical triplet ends at residue | 63 |
| According to UniProtKB , the second helical triplet ends at residue | 133 |
| According to UniProtKB , the third helical triplet ends at residue | 275 |

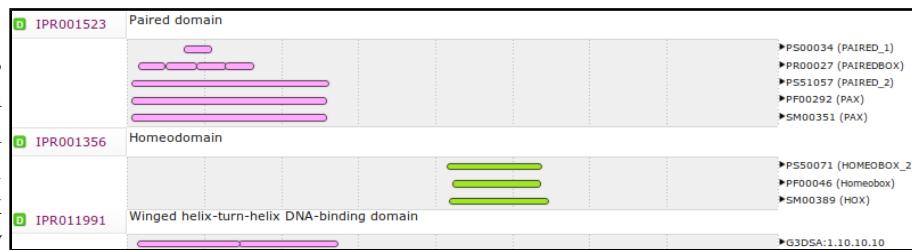
There is a point to recording these numbers ... honest! The second two helices of each triplet form a special sub-domain that we will read of (and search for with the relevant analytical software) later. Here we see the first indication of where these features may be.

¹⁴³ “the **snp135Common** table will only contain SNPs with a minor allele frequency \geq 1%”

Note the position of the Beta strands relative to the helix groups.

There are **3** Beta strands, according to **UniProtKB**. All are within the **Paired Box** domain. Two before the first helical triplet (residues **6** to **8** and **14** to **16**), and one in before the second helical triplet (residues **77** to **79**). Later you will run programs to predict the secondary structure of this protein. It will be interesting to compare your predictions with those of **UniProtKB**.

Beta strands precede the **2** helical triplets in the **Paired Box** domain but not that in the **Homeobox** domain. As will be seen just a little later, each of the helical triplets should include a **Helix-turn-helix** motif. A **Helix-turn-helix** preceded by Beta sheet structure(s) can be a **Winged helix-turn-helix**.



I think the absence of Beta Sheet(s) in the **Homeobox** may well be the reason that **GeneCards** (quoting **Interpro**) reported only two **Winged Helix-turn-helix** motifs, rather than three. That is, there is an **HTH** in the **Homeobox**, but not a **Winged HTH**.

Describe the arrangement of Helices within the two major domains of **PAX6**.

You have noted already that there are **nine** helices that occur in **three** groups of **three**. From the highlighted alignment it is clear that **two** helical triplets coincide with the **Paired** domain and **one** helical triplet with the **Homeobox** domain.

Note the extra sequence in **P26367-2** and where it starts.

In the rather stark **text** version¹⁴⁴ of **PAX6_HUMAN**, the **Sequence Variation (VAR_SEQ)** that define the difference between the canonical form of the **PAX6** protein and **isoform 5a** is recorded as:

| | | | | |
|-----------|----------------|-----------|-----------|-----------------------------------|
| FT | VAR_SEQ | 47 | 47 | Q → QTHADAKVQVLDNQN |
|-----------|----------------|-----------|-----------|-----------------------------------|

which translates literally to:

“the single amino acid, **Q**, in the **47th** residue position of the canonical protein is replaced by the **15** amino acids, **QTHADAKVQVLDNQN**, in the same position to form **isoform 5a**”

A more biologically orientated way of putting this might be to say that **isoform 5a** is defined by an insertion of an extra **14** amino acids, **THADAKVQVLDNQN**, after the **47th** amino acid of the canonical protein. As you will see later, the difference between the two isoforms is determined by the inclusion or exclusion of a single small exon of **42** base pairs during the construction of the mRNA.

How would you rationalise the reference to the mRNA entry **BX640762** here?

As you have already established, **BX640762** is genuinely a **PAX6** sequence and deserves its place in this list. However, you have already established that this sequence would not be found by an annotation search for the most obvious search term “**PAX6**”. So, I conclude this list was constructed either by using an annotation search with different keyword(s) or by using a sequence search producing a list of sequences that look like **PAX6** independent of what might be found in their annotation.

¹⁴⁴ You can follow the link I have built into this **PDF**, or you can view the **PAX6_HUMAN** entry in a number of formats using the links at the top of the entry page. **text | xml | rdf/xml | gff | fasta**

A quick look at **Prosite**:

What is the **Consensus pattern** for a **Paired domain**?

R-P-C-x(11)-C-V-S

Where in a **Paired domain** should the **Consensus pattern** occur?

The documentation declares the **Consensus pattern** to be derived from the amino acids between **34** and **50** of the **Paired domain**.

We use the region spanning positions 34 to 50 of the paired domain as a signature pattern. This conserved region spans the DNA-binding HTH located in the N-terminal subdomain. We also developed a profile that covers the entire paired domain, including the PAI and RED subdomains and which allows a more sensitive detection.

UniprotKB claims the **Paired domain** to start at amino acid **4**.

| | | | | |
|--------------------------|--------|---------|-----|--------|
| <input type="checkbox"/> | Domain | 4 - 130 | 127 | Paired |
|--------------------------|--------|---------|-----|--------|

This leads me to conclude the **Consensus pattern** to be between residues **38** and **54** of the entire protein. Which is exactly correct.

| | | | | |
|--------------------|-------------|------------|--------------------|-------------------|
| 10 | 20 | 30 | 40 | 50 |
| MQNSHSGVNQ | LGGVFVNNGRP | LPDSTRQKIV | ELAHSGA RPC | DISRILQVSN |
| 60 | 70 | 80 | 90 | 100 |
| GCVS KILGRY | YETGSIRPRA | IGGSKPRVAT | PEVVSKIAQY | KRECP SIFAW |

Knowing the rough location of this pattern will be useful later on.

How would you interpret this pattern?

The **pattern** is matched where there is:

| | | | | |
|--|---|---------------------------------|---|---------------------------------|
| An Arginine(R) | - | followed by a Proline(P) | - | followed by a Cystine(C) |
| followed by exactly 11 amino acids of any type x(11) | | | | |
| followed by a Cystine(C) | - | followed by a Valine(V) | - | followed by a Serine(S) |

The syntax for these patterns is slightly richer than implied by this example. Specifically:

- It is possible to use square brackets to indicate possible variation in a position. For example: **[VIL]** would match if a position that was any of a **Valine(V)**, **Isoleucine(I)** or **Leucine(L)**.
- Curly brackets can be used to indicate “anything except”. For example: **{P}** would match if a position was anything except a **Proline(P)**.
- Round brackets can be used to indicate ranges. For example: **[FY](2,4)** matches if at least **2**, but no more than **4** positions were either **Phenylalanine(F)** or **Tyrosine(Y)**.
- **L(0,2)** or **L(,2)** would match if there was between **0** and **2** **Leucine(L)**s.
- **A(2,)** would match if there were **2** or more **Alanine(A)**s

The minus signs between the elements of a pattern are optional.

How effective does the Technical section imply this pattern to be?

The **Technical section** claims that there are **58** sequences in **Swiss-Prot** that include a **Paired Box** domain and so should match this pattern. This claim assumes that all the sequences of **Swiss-Prot** are **100%** accurately annotated. A little optimistic, but one must have faith in something.

The **Technical section** notes that every one of these **58 Paired boxes** includes the pattern. detected by PS00034: 58 (true positives)

The **Technical section** further notes, with some small redundancy, that none of the “known” **Paired Boxes** go undetected either because they do not contain the pattern or because they are partial sequences. undetected by PS00034: 0 (false negative or 'partial')

The **Technical section** finally opines that there are **7 Swiss-Prot** sequences that definitely do **not** include a **Paired Box** that **do** match the **Paired Box** pattern. Other sequence(s) in UniProtKB/Swiss-Prot detected by PS00034: 7 false positives.

Not bad for such a simple strategy I would suggest, but not as good as the **PROSITE MATRIX** (i.e. **Hidden Markov Model, HMM**) that is evaluated just below the pattern. This also finds all the genuine **Paired Boxes**, but does not pick up any false positives.

| PAIRED_2, PS51057; Paired domain profile (MATRIX) | | | |
|---|--|--|--|
| <ul style="list-style-type: none"> Sequences in UniProtKB/Swiss-Prot known to belong to this class: 58 <ul style="list-style-type: none"> detected by PS51057: 58 (true positives) undetected by PS51057: 0 (false negative or 'partial') Other sequence(s) in UniProtKB/Swiss-Prot detected by PS51057: NONE. | | | |

Also, the performance of this pattern is not as immaculate as is suggested here, as will be touched on in another answer still to come.

How well does the secondary structure suggested by **Prosite** match that recorded by **Uniprot**?

Well, the homeobox is predicted by **UniProt** to be from residues **210-269**.

60 amino acids exactly as suggested by the **PROSITE** documentation.

Three homeobox helices are predicted by **UniProt** to be at:

| DNA binding ¹ | 210 - 269 | 60 | Homeobox |
|--------------------------|-----------|----|----------|
| Helix ¹ | 219 - 229 | 11 | |
| Helix ¹ | 237 - 246 | 10 | |
| Helix ¹ | 251 - 275 | 25 | |

Relative to the start of the protein

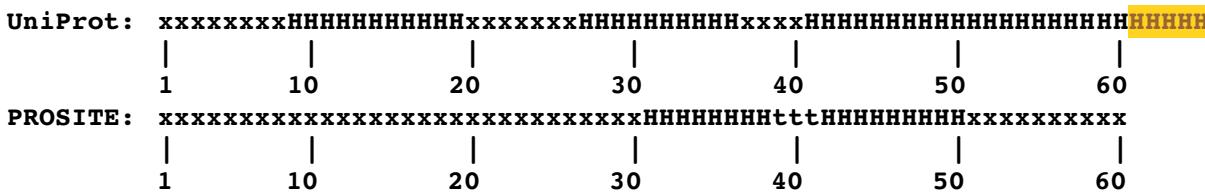
219 – 229
237 – 246
251 – 275

Relative to the start of the homeobox

009 – 019
027 – 036
041 – 065

No turn is predicted by **UniProt**. This is not too surprising as turns are not easy to predict. **PROSITE** suggests there should be a turn between just two helices, forming a **helix-turn-helix** region through which the domain binds DNA. **PROSITE** makes no mention of a third helix in front of the **helix-turn-helix** motif.

Diagrammatically:



PROSITE is short a helix and **UniProt** is short a turn, but what is left is broadly in the right place? If a trifle over long here and there? What an imperfect world we occupy.

How many **helix-turn-helix** motifs would you expect in the **homeobox** domain?

Just one, according to the **PROSITE** documentation at least.

Where (in amino acid positions) would you expect all the **PAX6 HTH** motifs to be?

HTH motifs are functional elements of one sort of **DNA-binding domain**.

In all, there are three **HTH**s in the **PAX6** protein for human. The second and third helix of each of the three helical triplets of the protein form an **HTH** motif of one sort or another. Computing just from the **UniProtKB** secondary structure predictions alone therefore, the three **HTH**s will be around:

039 → 063
099 → 133
237 → 275

| | | |
|--------------------------|-----------|----|
| Helix ⁱ | 23 – 34 | 12 |
| Helix ⁱ | 39 – 46 | 8 |
| Helix ⁱ | 50 – 63 | 14 |
| Beta strand ⁱ | 77 – 79 | 3 |
| Helix ⁱ | 81 – 93 | 13 |
| Helix ⁱ | 99 – 108 | 10 |
| Turn ⁱ | 114 – 116 | 3 |
| Helix ⁱ | 120 – 133 | 14 |
| Helix ⁱ | 219 – 229 | 11 |
| Helix ⁱ | 237 – 246 | 10 |
| Helix ⁱ | 251 – 275 | 25 |

The first two **HTH** motifs are in the **Paired** domain. The **PROSITE** documentation for **Paired** domain alone is not sufficiently specific to predict the position of these **HTH**s with residue number precision.

The crystal structures of prd and Pax proteins show that the DNA-bound paired domain is bipartite, consisting of an N-terminal subdomain (PAI or NTD) and a C-terminal subdomain (RED or CTD), connected by a linker (see). PAI and RED each form a three-helical fold, with the most C-terminal helices comprising a helix-turn-helix (HTH) motif that binds the DNA major groove. In addition, the PAI subdomain encompasses an N-terminal beta-turn and beta-hairpin, also named 'wing', participating in DNA-binding. The linker can bind into the DNA minor groove. Different Pax proteins and their alternatively spliced isoforms use different (sub)domains for DNA-binding to mediate the specificity of sequence recognition [4,5].

The third **HTH** is in the **homeobox** domain. The **PROSITE** documentation for a **homeobox** domain suggests this **HTH** starts at position **31** of the **homeobox** and continues to position **50**.

UniProtKB suggests the **homeobox** starts at residue **210**. So, an alternative suggestion of the position of the third **HTH** would be:

240 → 259

A schematic representation of the homeobox domain is shown below. The helix-turn-helix region is shown by the symbols 'H' (for helix), and 't' (for turn).

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxHHHHHHHHttHHHHHHHHxxxxxx
| | | | | | |
1 10 20 30 40 50 60

Close enough? You will predict the whereabouts of the **HTH**s programmatically later (now a **Supplementary Exercise**), with only partial success, as it is not an easy prediction. Also, there are a number of different types of **HTH**. The software is optimised for just one of the possibilities.

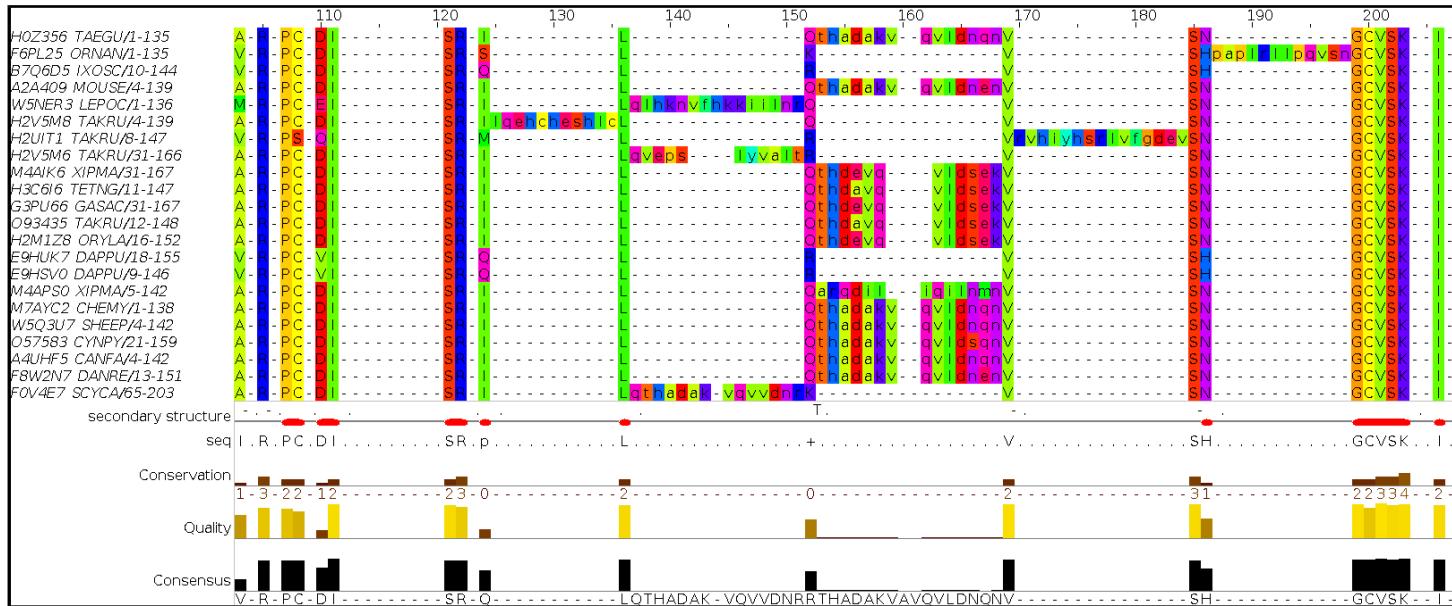
A quick look at Pfam:

Allowing for the distorted numbering of the alignment, how would you interpret the extra 14 or so amino acids that some sequences appear to have around position 150-170?

These must be the extra 14 amino acids that define the second **PAX6** isoform. The sequences that include the extra amino acids must represent **isoform 5a** proteins.

All the residues represented by lower case letters are insertions, relative to the **Seed HMM profile** for a **Pfam Paired** domain.

How might you interpret the way that **HMMER3** suggests that some sequences have a similar insertion in a slightly different places to its neighbouring proteins?



I do not believe the extra insertions and regard the whole alignment as suspiciously scrappy. I have to reluctantly conclude **HMMER3** is not doing a very good job. The previous aligner (**HMMER2**) used by **Pfam** produced a far more convincing (single insertion) alignment. There must be a good reason why **HMMER3** is preferred to **HMMER2**. Apparently it is faster, but ... it does not seem to work? I must be missing something. This alignment even includes empty columns! That is positions in which every single aligned sequence is gapped (i.e. represented by a “-”), which really cannot make any sense at all¹⁴⁵.

Practically, the indifferent quality of this alignment really does not matter that much. It is the **HMM profile** computed from the **Seed alignment** that is used to represent a **Pfam Paired** domain and this it does very effectively. The alignment here is just for show. It still seems a shame that it is not more convincing.

The main complaint, for the region illustrated, is that there surely should only be one 14 residue insertion in this alignment. There is evidence here of 5 or 6!! I am not convinced that the different insertions would not align quite satisfactorily with each other, although I admit to not having looked that closely. In order to make this observation clear in the picture above, I had to reorder the sequences a trifle. This is very easy with **Jalview**. I first sorted the sequences by length (**Calculate** → **Sort** → **by Length**) and then moved a few individual sequences **Up/Down** as required (Click on the sequence name to select and the use the **Up/Down** arrow keys to move your section).

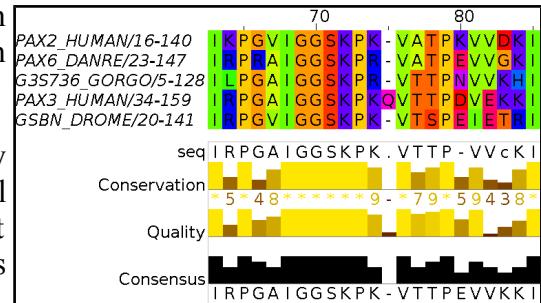
In passing, note the positions of the highly conserved residues of the **PROSITE** pattern for **Paired** domain. The **RPC** starts at position 105 and is shown as not entirely consistent (one sequence have an **S** where the **C** should be and at least one other sequence, somewhere out of sight, having an insertion after the **R**). The **CVS** is 100% conserved for the sequences in view and starts at position 200. So, the **isoform 5a** insertion occurs in the middle of the **PROSITE** pattern for a **Paired** domain. As will be discussed again later, this has to make the pattern **RPCx(11)CVS** very much less than useful at detecting **isoform 5a** **Paired** box sequences.

¹⁴⁵ You can prove this by selecting **Remove Empty Columns**, from the **Jalview Edit** menu. You will observe the alignment is reduced by width.

Note down the position in the alignment where all but one seed sequence has a gap.
Note the consensus character at this point and its most logical interpretation.

In residue position **75** of the seed alignment, **4** of the **5** protein sequences are gapped. Only one sequence, **PAX3_HUMAN**, has an amino acid recorded, a **Q** (Glutamine).

The **Consensus** character at this point is “-”. **Jalview** has its own way to calculate the **Consensus**. Read the [documentation](#) for the official explanation. Informally: for positions where there is no dominant amino acid code, + means “more than one possibility”, - means “predominantly a gap”.



How is the heavily gapped position of the seed alignment represented in its **HMM Logo**?
How would you interpret the **Logo** in this region?

The heavily gapped position of the seed alignment is position **75**. In this position, **4** of the **5** aligned sequences have been gapped, the remaining sequence has a **Q**.

This position does not appear in the **Logo** (although there is a position **75** ... which relates to position **76** of the alignment ... which seems a bit silly to me!). This implies that the **HMM** represents the data at position **75** thus:

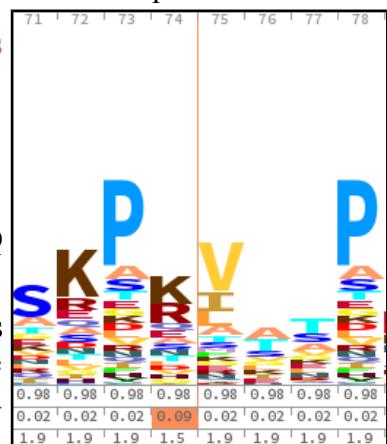
“Generally not present, but a relatively high chance of an insertion which is generally a **Q**”

The alternative, equivalent, representation would be:

“Generally a **Q**, but a relatively high probability of a deletion”

Had the second alternative been selected, the **Logo** would have shown a healthy **Q** at position **75**.

A thin brownish line is placed in the **Logo** to indicate where position **75** was omitted. The **Logo** is not a precise enough representation to clearly show all the details of the chance of an insertion and whether that the insertion is likely to be a **Q** but this will be recorded in the **HMM** itself.



A quick look at Prints:

How many links to PRINTS would you expect?

Two surely. It should be clear by now that we are investigating a protein with **two** major domains, a **Paired Box** and a **Homeobox**. It is reasonable to expect that all the domain database searches would find both these domains. PRINTS shows only the presence of the **Paired Box** domain.

What if anything, do you think is missing?

So, what is missing is evidence of the **Homeobox** domain. PRINTS has detected the **Paired Box** but has entirely missed the **Homeobox** domain. All the domain searches work slightly differently and none always pick up everything that they should. This is why the best strategy is not to rely on just one domain search but to always run them all¹⁴⁶. That one search occasionally misses something is to be expected, for all the searches to fail together should really not happen.

That it is PRINTS that fails in this instance should not be taken to mean that PRINTS is an inferior domain database. As you will see later on in the exercises, PRINTS only fails to detect the **Homeobox** by a whisker. The presence of a **Homeobox** domain is detected, but at a strength below that required for PRINTS to record a hit.

¹⁴⁶ Interpro allows you to do this easily, as hopefully we have discussed and as you will see for yourself later on.

A quick look at the **cluster databases**:

What was the **seed sequence** upon which this cluster was built?

D3DQZ8

What do you imagine a **seed sequence** might be?

The seed sequence is the longest sequence in a cluster.

The UniRef databases are generated in a hierarchical fashion where:

- UniRef100 clusters are generated first using sequences from UniProtKB and UniParc databases
- UniRef90 clusters are generated using UniRef100 seed sequences (longest sequence in a cluster)
- UniRef50 clusters are generated using UniRef90 seed sequences

What is the **Representative sequence** protein for this cluster?

P26367

What do you imagine a **Representative sequence** might be?

The representative sequence is the top sequence in a cluster.

All the proteins in each cluster are ranked to facilitate the selection of a biologically relevant representative for the cluster. The representative sequence (ranked first) is selected based on the following criteria:

1. quality of annotation: order of preference is a member from UniProtKB/Swiss-Prot then UniProtKB/TrEMBL and last is UniParc
2. meaningful name: members with protein names that do not contain words such as hypothetical, probable etc. are preferred
3. organism: entries from model organisms are preferred
4. sequence length: longest sequence is preferred

How many sequences are from **UniProtKB/Swiss-Prot** and how many from **UniprotKB/TrEMBL** (Look at the Dataset pull down Menu)?

UniProtKB(10)

UniProtKB/Swiss-Prot(2)

UniProtKB/TrEMBL(8)

| 10 members from 8 organisms | |
|-----------------------------|---|
| Dataset | |
| UniProtKB (10) | ▼ |
| UniProtKB (10) | ▼ |
| UniProtKB/Swiss-Prot (2) | ▼ |
| UniProtKB/TrEMBL (8) | ▼ |

Given your last answer, how would you interpret the colours of the stars in the **Status** column?

| 10 members from 8 organisms | | Taxonomy | Members | | Customize | | | |
|-----------------------------|-------------------|----------|--------------|--------|--|--|------------------|--------|
| Dataset | Cluster member(s) | | Entry name | Status | Protein names | Organisms | Related Clusters | Length |
| UniProtKB (10) | P26367 | H | PAX6_HUMAN | ★ | Paired box protein Pax-6 | Homo sapiens (Human) | | 422 |
| | P63015 | H | PAX6_MOUSE | ★ | Paired box protein Pax-6 | Mus musculus (Mouse) | | 422 |
| | Q66SS1 | H | Q66SS1_HUMAN | ★ | Paired box gene 6 isoform a | Homo sapiens (Human) | | 422 |
| | F2Z5M7 | H | F2Z5M7_PIG | ★ | Uncharacterized protein | Sus scrofa (Pig) | | 422 |
| | F6SAR0 | H | F6S4R0_CALJA | ★ | Uncharacterized protein | Callithrix jacchus (White-tufted-eared marmoset) | | 422 |
| | F7C9R7 | H | F7C9R7_MACMU | ★ | Paired box protein Pax-6 isoform a | Macaca mulatta (Rhesus macaque) | | 422 |
| | G1P774 | H | G1P774_MYOLU | ★ | Uncharacterized protein | Myotis lucifugus (Little brown bat) | | 422 |
| | H0XKU3 | H | H0XKU3_OTOGA | ★ | Uncharacterized protein | Otolemur garnettii (Small-eared galago) (Garnett's greater bushbaby) | | 422 |
| | I7G9J6 | H | I7G9J6_MACFA | ★ | Macaca fascicularis brain cDNA clone: OorA-12050, similar to human paired box gene 6 (aniridia, keratitus) (PAX6), mRNA, RefSeq: NM_000280.1 | Macaca fascicularis (Crab-eating macaque) (Cynomolgus monkey) | | 422 |
| | D3DQZ8 | H | D3DQZ8_HUMAN | ★ | Paired box gene 6 (Aniridia, keratitus), isoform CRA_a | Homo sapiens (Human) | | 456 |

Hover over the column heading **Status** to confirm this conclusion.

| Entry name | Status | Protein names | Organisms | Cluster name | Length |
|------------|--------|--------------------------|----------------------|--------------|--------|
| PAX6_HUMAN | ★ | Paired box protein Pax-6 | Homo sapiens (Human) | | 422 |

Indicates if the entry has been manually reviewed (UniProtKB/Swiss-Prot; gold star) or automatically annotated (UniProtKB/TrEMBL; grey star)

Which sequences react to the **Annotation** request, and why?

The **SwissProt** sequence react, the **TrEMBL** ones do not. Only the **SwissProt** entries have quality annotation.

Can you rationalize why one of the sequences is allowed to be different to all the others?

XXXXX

After viewing this **UniRef100** entry, how “non-redundant” would you say was **UniprotKB**?

XXXXX

Why do you suppose it might be useful to have identical sequences in **UniprotKB**?

XXXXX

From your investigations using Ensembl:

Is it a gene dense region?

Just in case you had forgotten, the region in question is **P13**.

Is it gene dense? A bit less than average I would say. Not a vital question, in the particular, but it is interesting how gene density seems vary quite substantially. **P12**, for example, is a bit of a desert! In contrast, several parts of **Q13** are very well endowed, particularly with protein coding genes.

What about Variation density?

Summary:

It is the **Variations** column to which I draw your attention here. Uniform density over most of the chromosome is suggested I think? Well, that is barring a couple of small peaks each side of a barren centromere. This was a much more interesting question before **Ensembl** included the entire **dbSNP** database from the **NCBI**. Variations were relatively sparse before this event and the density varied with greater whimsicality.

Full Answer:

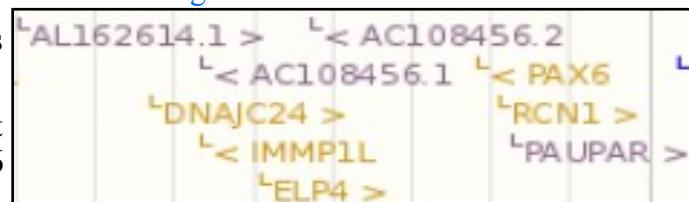
2015.06.01: This display was broken! The cause was that a massive increase in the size of the **dbSNP** database exceeding the capacity of the display!. The boys (and girls) of **Ensembl** suggested they may have to move to a logarithmic scale in order to cope.

2015.07.18: All fixed. Not sure if the logarithmic scale was implemented, but the picture now looks quite convincing, if bland. The picture in the book is now current. There are now so many variations it is difficult to read much into this picture at all? Superficially, the distribution of variations looks even more uniform throughout the chromosome than it did previously. This impression may well be exaggerated by the use of a logarithmic scale? The “peaks” around the centromere are certainly more subdued.

Can you also see the two other genes you might have expected to be in this region?

PAX6, **ELP4** and **RCN1** can be clearly seen in positions predicted by the annotations you found earlier¹⁴⁷.

The “>” characters for **ELP4** and **RCN1** both indicate that these genes are on the strand opposite to that where **PAX6** resides. This too will also have expected.



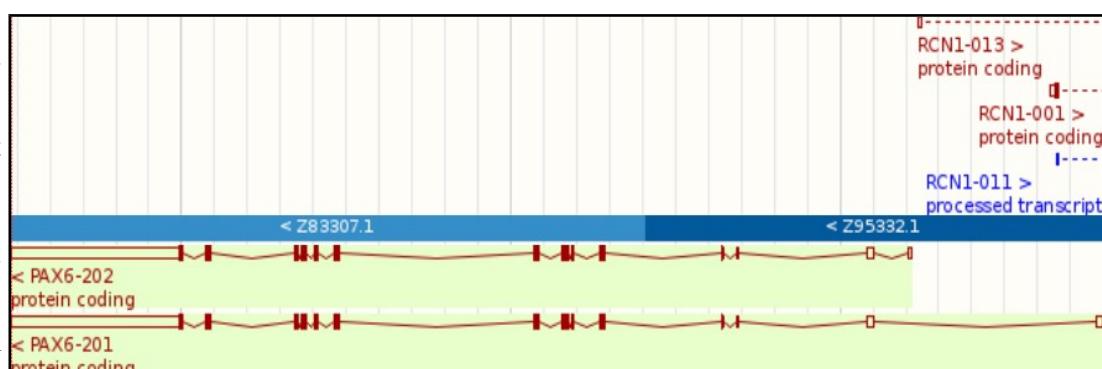
What are the (familiar?) contig numbers containing all of **PAX6**?

The portions of the genomic clones **Z83307** and **Z95332** needed to represent the longest transcript of **PAX6** are clear to see, represented as alternating dark and light blue bars.

Note the “<” characters in each bar indicating that both clones were reversed and complimented (relative to their representation in **GenBank/EMBL-Bank**) in order to be assembled with all the other contig contributions to the entire sequence of **Chromosome 11**. In the **EMBL-Bank** version of both these clones, **PAX6** was suggested to be on the forward strand. In **Ensembl**, **PAX6** is shown below the blue contigs bar, implying that it is on the reverse strand of **Chromosome 11** as a whole.

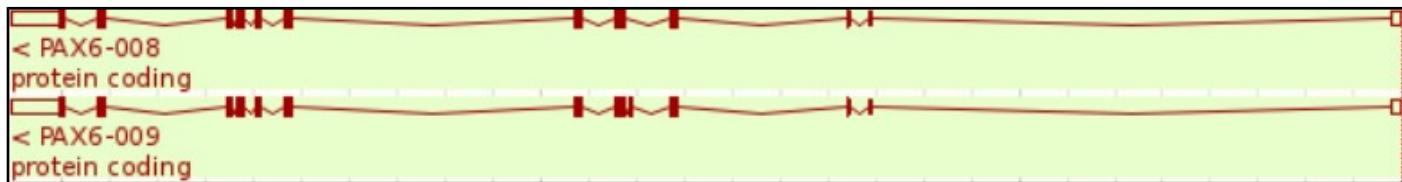
Note the beginnings of some **RCN1** transcripts on the forward strand. **Ensembl** suggests, mostly between UTRs and never involving coincident exons, an overlap between the 5' UTR of some transcripts of **PAX6** and the 3' UTR of some transcripts of **RCN1**.

There is no sign of **ELP4** in this view. The part of this gene included in **Z83307** does not overlap with the **PAX6** region and is so does not appear here.



¹⁴⁷ You need to allow that the gene names occupy much more space than the genes at this scale. The next picture gives a more useful impression.

Explain the visible differences between the coding exons of transcripts **PAX6-008** and **PAX6-009**?



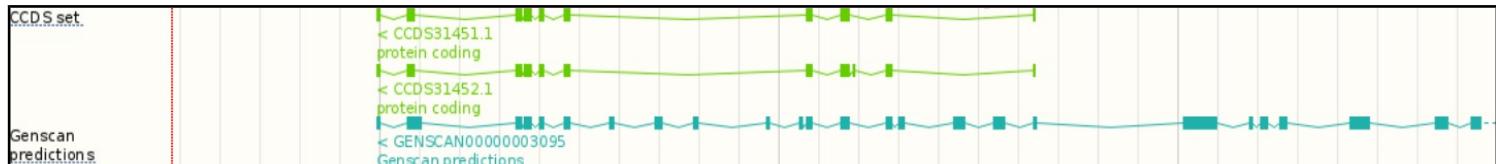
Of course, one cannot be certain that all differences between these transcripts can be observed from a picture.

For complete accuracy, one has to view the textual representations, however, there is one clear difference observable here. There is an extra coding exon in **PAX6-009**, the 5th, to be particular (remember you must read the transcript from right to left as **PAX6** is on the reverse strand of the Chromosome).

The inclusion/omission of the 5th exon, a very small coding exon, must result in alternative protein products (isoforms) for each of the two transcripts. Maybe this small exon is the source of the extra 14 amino acids that define **isoform 5a** of **PAX6**? This should be clearly confirmed/denied when we get to look at the transcripts in more detail. It must be a good bet though? There are only two isoforms with sequence after all.

Or ... maybe the answer to the next question will be enough to convince you?

[What PAX6 exon of note has Genscan omitted to predict?](#)



There are two **CCDS** set hits, one for each isoform. The extra coding exon that defines **isoform 5a** can be seen clearly in the upper **CCDS** hit (3rd coding exon in from the right, as we are looking at an analysis of the reverse strand of the gene here, that means the 3rd coding exon from the start of the gene). This extra coding exon is missed by **Genscan**, probably because of its size. **Genscan** does predict all the other coding exons (plus extras) and makes a reasonable shot at the non-coding exons also. You could see **Genscan** in action again in an optional exercise.

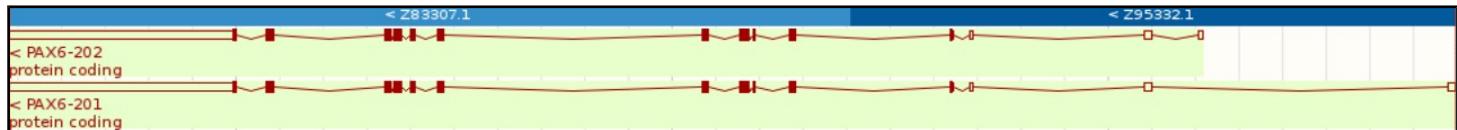
For pedants only. Can you see how to identify the **Havana** predictions from the **Ensembl** predictions by the way they are numbered?

The numbering for transcripts predicted by the **Vega-Havana** team commences at **001**.

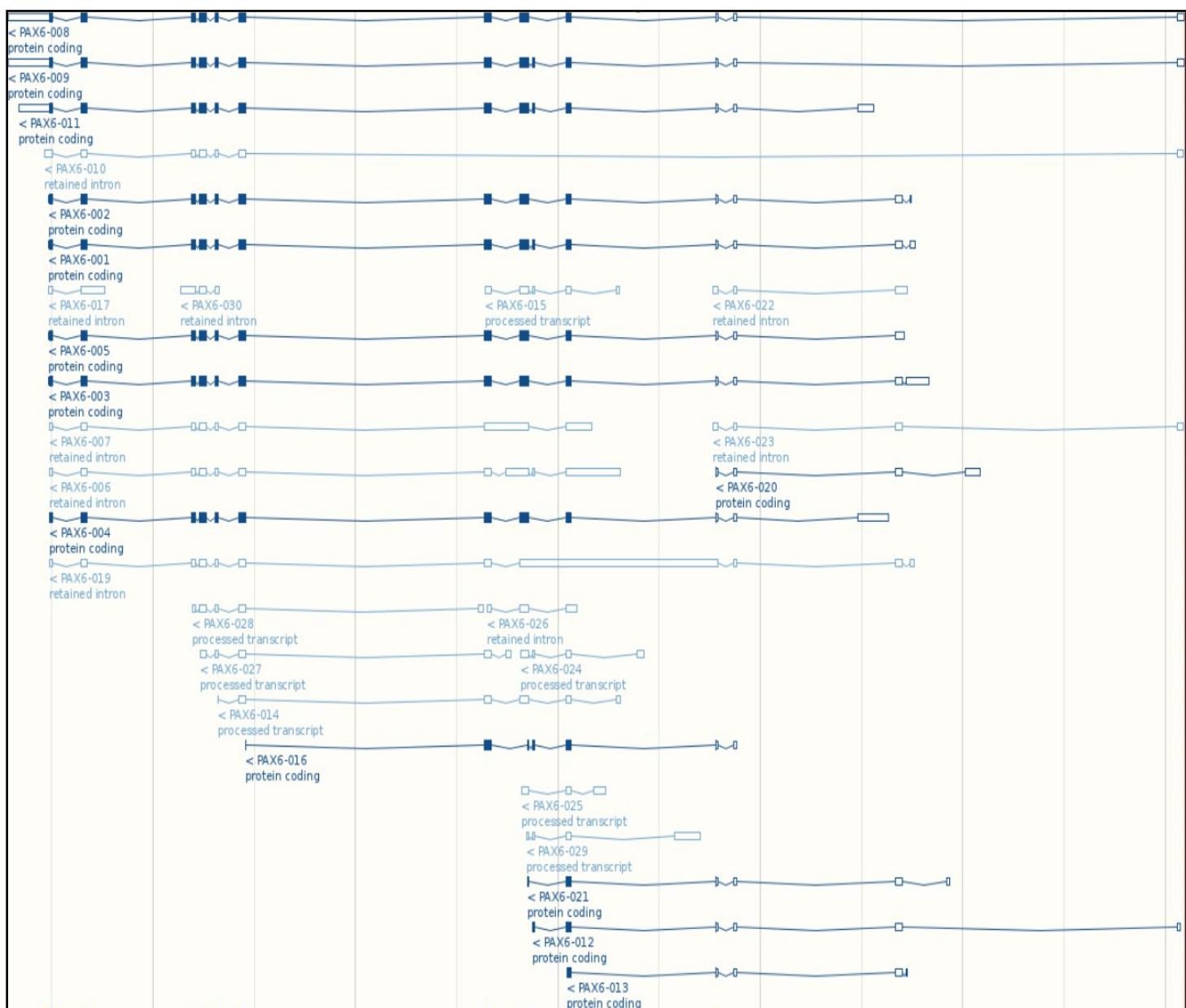
The numbering for transcripts predicted by the **Ensembl** pipeline commences at **201**.

When a transcript is agreed upon by both predictive methods, the **Vega-Havana** numbering takes precedence.

In this example, there are just two transcripts that are predicted by the **Ensembl** pipeline but not by the **Vega-Havana** team. They are the transcripts **PAX6-201 & PAX6-202**.



You can confirm this (if you really must!) by looking for differences between the **Vega-Havana** only track and the **Merged Ensembl and Havana genes** track. **PAX6-201 & PAX6-202** are the only omissions from the **Vega-Havana** only track.



Note the number of RefSeq mRNAs and RefSeq proteins associated with Ensembl transcripts predictions.

Which of the 20 RefSeq mRNAs reported by GeneCards can be seen here?

Why would you suppose these mRNAs were selected and the others ignored?

Most of the top few protein coding transcripts are associated with RefSeq mRNAs.

The mRNAs selected are the 7 whose accessions codes commence NM_. These are referenced with their protein sequences whose accession codes start NP_

GeneCards also records the presence in of further 8 RefSeq mRNAs with accession codes

beginning XM_ and associated proteins with accession codes starting XP_. These 8 mRNAs do not appear here.

The NM_/NP_ sequences are supported by better evidence than the XM_/XP_ sequences. I suspect that Ensembl regards only the NM_/NP_ RefSeq entries of sufficient quality to predict transcripts.

It is curious that one transcript is associated with two RefSeq mRNAs? That does not seem quite logical to me, unless the mRNAs are identical, which they are not! An investigation for another time I think.

Using the evidence of the protein alignments, which PAX6 isoforms do the fruitfly orthologues most resemble?

The protein used to represent PAX6 human is consistently ENSP00000404100. This can most easily be confirmed by clicking on the  View sequence alignments link to view all orthologous protein alignments at once. This is the protein sequence of isoform 5a, probably chosen as it is the longer option (436 amino acids as opposed to 422) and so (from the crude informatics viewpoint) represents more information.

As discovered earlier from GeneCards, there are two fly orthologues with the gene names ey and toy. Ensembl agrees, which should not be surprising as GeneCards consults Ensembl for orthologue information. Looking at the first few lines of the protein alignments for these genes, it is clear that that 14 amino acid insert that defines isoform 5a (THADAKVQVLNDNQN) is not present in either. It is therefore reasonable to conclude that the representative fly proteins are both closest to the canonical protein sequence of PAX6 human (isoform 1).

| | |
|--|--|
| ENSP00000404100/1-436
FBpp0099810/1-898 | MQN-----SHSGGVNQLGGGVFVNGRPLPDSTRQKIVELAHS
GKPSPTEAVEASTASHPHSTSSYFATTYYHILTDCEHSGVNLQGGVFVGRPLPDSTRQKIVELAHS |
| ENSP00000404100/1-436
FBpp0099810/1-898 | KIVELAHSGARPCDISRILQTHADAKVQLDNQNVSNGCVSKILGRYYETGSIRPRAIGG
KIVELAHSGARPCDISRILQ-----VSNGCVSKILGRYYETGSIRPRAIGG |
| ENSP00000404100/1-436
FBpp0099810/1-898 | SKPRVATPEVVSKIAQYKRECP SIF AWEIRDRLSEGVC TNDNIPSVSSINRVLRNLASE
SKPRVATAEVVSKISQYKRECP SIF AWEIRDRLQENVC TNDNIPSVSSINRVLRNLAAQ |
| ENSP00000404100/1-436
FBpp0088249/1-543 | -MQN-----SHSGGVNQLGGGVFVNGRPLPDSTRQKIVELAHS
MMLTTEHIMHGHPHSSVGQSTLFGCSTAGHSGINQLGGVYVNGRPLPDSTRQKIVELAHS |
| ENSP00000404100/1-436
FBpp0088249/1-543 | GARPCDISRILQTHADAKVQLDNQNVSNGCVSKILGRYYETGSIRPRAIGGSKPRVATP
GARPCDISRILQ-----VSNGCVSKILGRYYETGSIKPRAIGGSKPRVATT |
| ENSP00000404100/1-436
FBpp0088249/1-543 | EVVSKIAQYKRECP SIF AWEIRDRLSEGVC TNDNIPSVSSINRVLRNLASEKQQMGADG
PVVQKIADYKRECP SIF AWEIRDRLSEQVCNSDNIPSVSSINRVLRNLASQKEQQAQQQ |

Protein alignment for ey

Protein alignment for toy

Well, maybe also it is not that simple? I would not be surprised If there were isoforms for ey and/or toy that were roughly equivalent to human isoform 5a. The alignment displayed could well reflect the relatively arbitrary choice of Ensembl as to which isoform it decides to use for the alignments, rather than any deep and meaningful biological truth. Already you can see that Ensembl prefers the (presumably) less important human isoform, merely because it is longer (more letters to match). Again, useful though these displays are, caution is required before reading too much “biology” into them.

Ensembl does not pick up the **prd** fruitfly homologue to **PAX6** mentioned elsewhere? Again, I wonder why. Mind you, **Ensembl** does only claim “**Selected orthologues**”? Still **prd** is a pretty important one to pass over!

Do the Paralogue reports of GeneCards and Ensembl agree? If not, can you explain the discrepancies?

Well, yes they do agree, so there are no discrepancies to explain. Both sources now agree that there are **9 PAX** genes in the human genome. As for orthologues, hardly surprising as **GeneCards** consults **Ensembl** for paralogue information.

I left the question here as recently there was disagreement due to misinterpretation of the **Ancestral taxonomy** field. I wanted to make the point that such small discrepancies are not uncommon and one should therefore be wary. A small price to pay for such immediate access to such volumes of information I suggest.

Which isoform of **PAX6** has been chosen for the alignments, and why would you suppose it was selected?

For these alignments, as for the orthologues, **Ensembl** consistently uses the same protein (**ENSP00000404100**). This is **isoform 5a** which is again used, because it is longer. Never mind the biology, for the computer's purposes, longest is best. It is more likely to match things because there is more of it. Sophisticated what!

```

ENSP00000404100/1-436 -----MQN-----S-----HSGVNQLGGVFVNGRPLPDSTRQKIV
ENSP00000364524/1-520 MAALPGTVPRMMRPAPGQNYPRTGFPLEVSTPLGQGRVNQLGGVFINGRPLPNHIRHKIV
*: * . : . * *****:*****: *:***

ENSP00000404100/1-436 ELAHSGARPCDISRLQTADAKVQVLNDQNVSNGCVSKILGRYYETGSIRPRAIGGSKP
ENSP00000364524/1-520 EMAHHGIRPCVISRQLR-----VSHGCVSKILCRYQETGSIRPAGAIGGSKP
*:*** * *** * *: *:***** * * ***** * ***** *****

ENSP00000404100/1-436 -RVATPEVVSKIAQYKRCPSIFAWEIRDRLSEGVCNDNIPS--VSSINRVLRNLAS-
ENSP00000364524/1-520 RQVATPDVEKKIEEYKRENPGMFSWEIRDRLKDGHCDRSTVPSGLVSSISRVLRIKFGK
:*****: * . ** ;**** . ;*:*****:;* * . :** * . ***: * *****: ****

```

The example is the alignment with **PAX7**.

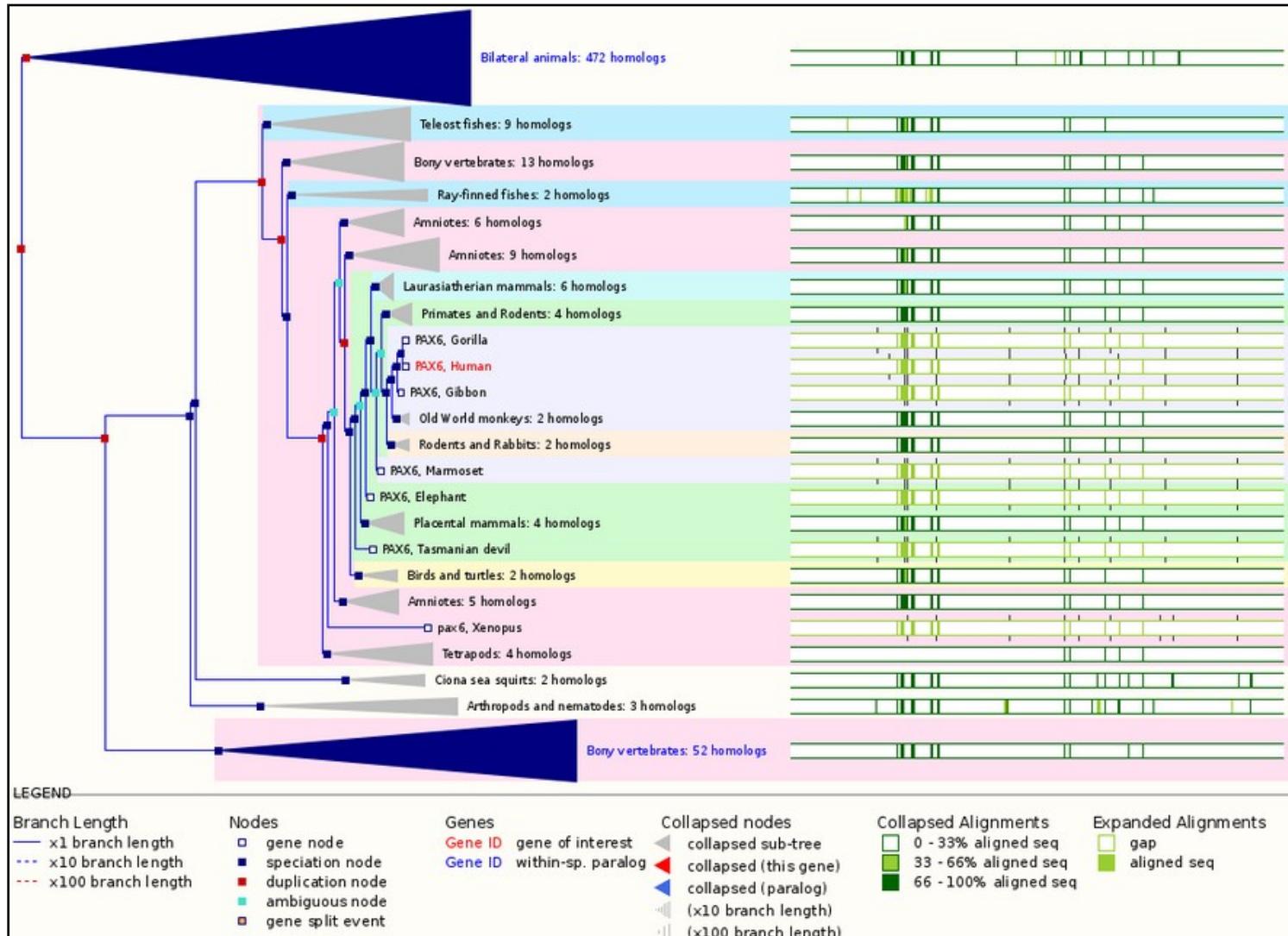
Which isoform is most common amongst the paralogues?

What a cruel and pointless question! As for the orthologues, the way I tried to find a simple answer was to click on the [View sequence alignments](#). In both cases, vaguely hoped I would be shown all the orthologues/paralogues compared with each other in one go. No such luck, although I now see why. That alignment would be very messy outside the **PAX** regions. Neither the orthologues nor the paralogues claim to be similar over their entire length after all.

Scanning quickly down the eight pairwise protein alignments, you should be able to see that all involve **isoform 5a** of **PAX6** with parologue sequences that lack the 14 amino acids insert. This proves nothing beyond the fact that **Ensembl** chooses to use what is probably the canonical form for the eight paralogues. There could easily also be an **isoform 5a** equivalent for every parologue.

An unanswerable question, I suggest? Well, a question for which a complete answer would require further investigation at least. I leave it in, as it does provoke some thought ... possibly?

The Gene Tree, as promised. Click here to return to the Instructions.



Some matching sequences offer no support for the 6th exon from the right. Why do you suppose this is?

The 6th exon from the beginning of the transcript (the right of the display) is that whose inclusion defines **isoform 5a**. All **mRNA/cDNA/protein** sequences representing the canonical **PAX6** human protein will not include this exon. This will be made absolutely apparent when you look at the textual representation of the exons very shortly.

However, canonical sequences can be useful as supporting evidence for all individual exons, excluding the 6th, so several are included in the supporting evidence display.

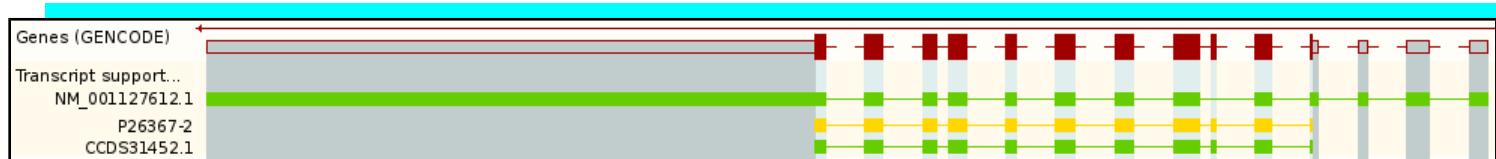
Why is there no protein or **CCDS** evidence for exons 1, 2 and 3?

CCDS stands for **Consensus CoDing Sequence**. All **CCDS** sequences are just the coding regions of genes. They do not include introns or **3'/5' UTRs**. Accordingly, there should not be (and is not) any **CCDS** evidence for exons **1, 2 or 3** as these exons include no protein coding regions.

Until recently (mid-2014), the **RefSeq** mRNA match in the **Transcript evidence** section did not match all exons. Was this logical?

This is a problem that has gone away now with the discovery of a **RefSeq** mRNA that exactly supports this transcript. Previously, the best that could be found was the **RefSeq** mRNA **NM_001127612**, which lacked the **6th** exon.

I include here the, now obsolete answer to this question. Perhaps a little pedantic, but I want to retain the particular point that **RefSeq** mRNAs are not perfect and the general point that we are looking at good, but still flawed, predictions here. One should always retain a modicum of scepticism when using these resources.



Not really. If this transcript is real, there must be an **mRNA** that matches its every exon, including the **6th, isoform 5a**, exon. It would seem there is no such **mRNA** sequence in **RefSeq** however. Ideally, there would be.

The problem is that **RefSeq** mRNAs are not usually the sequence of a single **mRNA**. They are a composite of a number of sequences assumed to represent the same biological entity. Things can go wrong, as they probably have here. The **RefSeq** construct suggests a canonical **mRNA**, **Ensembl** suggests an **isform 5a mRNA**. Well, one of them is probably right.

Ensembl first uses **CCDS** matches to establish the presence of the gene and all its possible isoforms. The **RefSeq** matches are primarily required to establish various forms of the **UTRs** for each prediction of a coding region. Here **Ensembl** has chosen to believe the combination of the **UTRs** suggested by **NM_001127612** and the coding region suggested by **CCDS31452**. **Ensembl** must be assuming that the **RefSeq mRNA** is not **100%** correct. This is clearly possible, but I do not regard the reasoning of **Ensembl** as particularly transparent, particularly as there is another **CCDS** match that would entirely support the **RefSeq** evidence?

How many exons are there in this transcript?

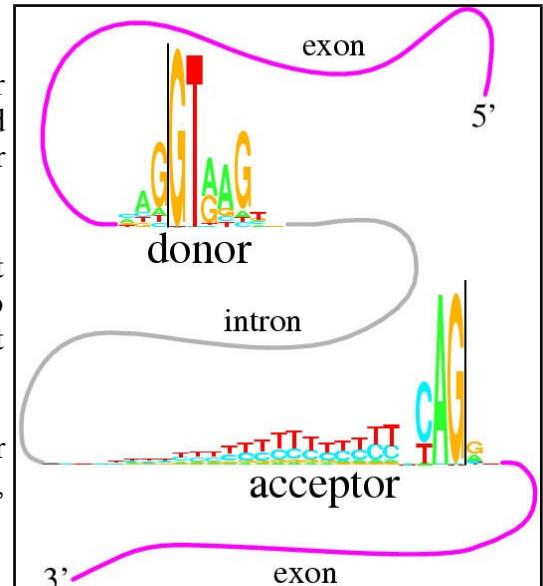
14, I think the relevance of this question has reduced over the aeons. I certainly cannot recall clearly why I asked?

What are the first two bases and what are the last two bases of nearly every intron?

As you are probably well aware, introns are highly conserved at their ends. They typically begin with **GT** and end with **AG**. This rule is obeyed by all but one of the introns of this transcript (**intron 3-4** starts **GC** rather than **GT**).

As the cartoon suggests, the conservation does not apply just to the first and last two bases, but that is where the conservation is most strict. So strict that when exceptions from this rule were sought in the databases, it was thought most of the deviations were due to annotation error!

The cartoon also suggests that introns have **C/T rich regions** towards their ends. This too is clearly evident in most of the introns of this transcript, even though only small parts of the exons are displayed.



How long is the sixth exon and why would this concur with your expectations?

It is **42** base pairs long, so it codes for **14** amino acids. Specifically, it codes for the **14** extra amino acids that define **isoform 5a**.

Explain the **Start Phase** and **End Phase** columns?

An exon/intron boundary can occur anywhere in a codon. The **Start** and **End Phases** record how an intron has been inserted into a coding region with respect to the coding reading frame.

If an exon ends at the end of a codon, then its **End Phase** is **0**.

Clearly, the next exon must begin at the start of a codon. Its Start Phase is **0**.

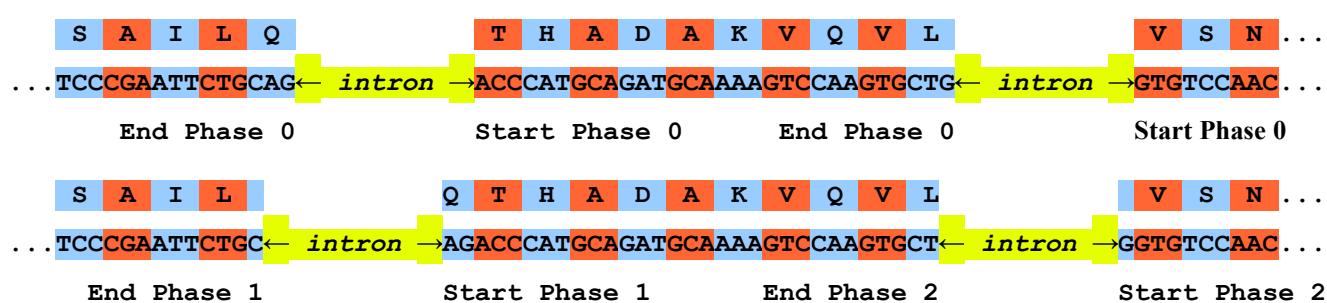
If an exon ends after the first base of a codon, then its **End Phase** is **1**.

Clearly, the next exon must begin after the first base of a codon. Its **End Phase** is **1**.

If an exon ends after the second base of a codon, then its **End Phase** is **2**.

Clearly, the next exon must begin after the second base of a codon. Its **End Phase** is **2**.

I attempt a picture, though I am sure that is clear? I just like pictures, and lots of colours.



Where is the start and end of the **Prosite Paired Box** pattern (**R-P-C-x(11)-C-V-S**)?

Where, in relation to the pattern, are the extra **isoform 5a** amino acids?

Why might the positions of these two features be significant?

The pattern **RPCxxxxxxxxxCVS** is pretty easy to spot, but the **14** amino acid insertion of **isoform 5a** (**THADAKVQVLDNQN**) has landed right in the middle of the pattern!

```
MQNSHSGVNQLGGVFVNGRPLPDSTRQKIVELAHSARPCDISRILQTHADAKVQVLDNQ
NVSNCVSKILGRYYETGSIRPRAIGGSKPRVATPEVVSKIAQYKRECPEIFAWEIRDRL
LSEGVCCTNDNIPSVSSINRVLRLASEKQOMGADGMYDKLRMLNGQTGSWGTRPGWYPPGT
SVPQQPTQDGCCQQEGGGENTNSISSNGEDSDEAQMRLQLKRKLQRNRRTSFTQEQUIALE
KEFERTHYPDVFARERLAALKIDLPEARIQVWFSNRRAKWRREEKLRNQRRQASNTPSHIP
ISSSFSTS VYQPIPQPTT PVSFTSGSMLGRTDTALTNTY SALPPMPSFTMANNLPMQPP
VPSQTSSYSCMLPTSPSVNGRSYDTYTPPHMQTHMNSQPMGTS GTTSTGLISP GVSVPVQ
VPGSEPDMSQYWPRLQ
```

This is very significant as far as the efficacy of the **PROSITE** pattern is concerned. Despite the claim of the **PROSITE** documentation that the pattern picks up all known **Paired** domains, it is not going to work on any **isoform 5a** protein. This claim relies on the fact that all the **PAX** proteins in **SwissProt** are represented by their canonical sequence. The very common **isoform 5a** is consistently recorded as a **FEATURE**, not search by the pattern matching software.

In order to detect just the **PAX isoform 5a**, the pattern would have to be:

R-P-C-x(25)-C-V-S

To detect both isoforms, using just one pattern:

R-P-C-x(11,25)-C-V-S

would work, but would be insufficiently specific and would generate far too many false positives. These sort of patterns are useful, but only with caution. They are valuable because of their simplicity, but very fragile.

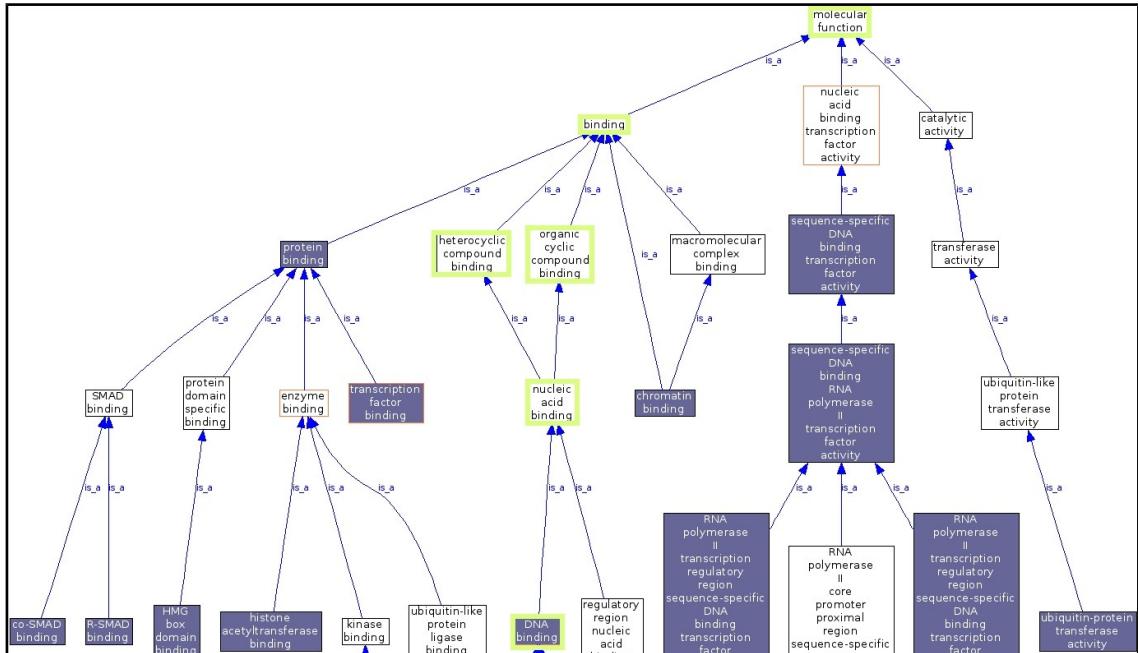
Give an example of the most specific terms represented?

Give an example of the most general terms?

I would love to put the whole graph here, but ... they are a bit big, so I will restrain myself to two sections.

The **Gene Ontology (GO)** terms are of three categories defining separately the **molecular function**, **cellular component** and **biological process** of a protein. So, there are three graphs.

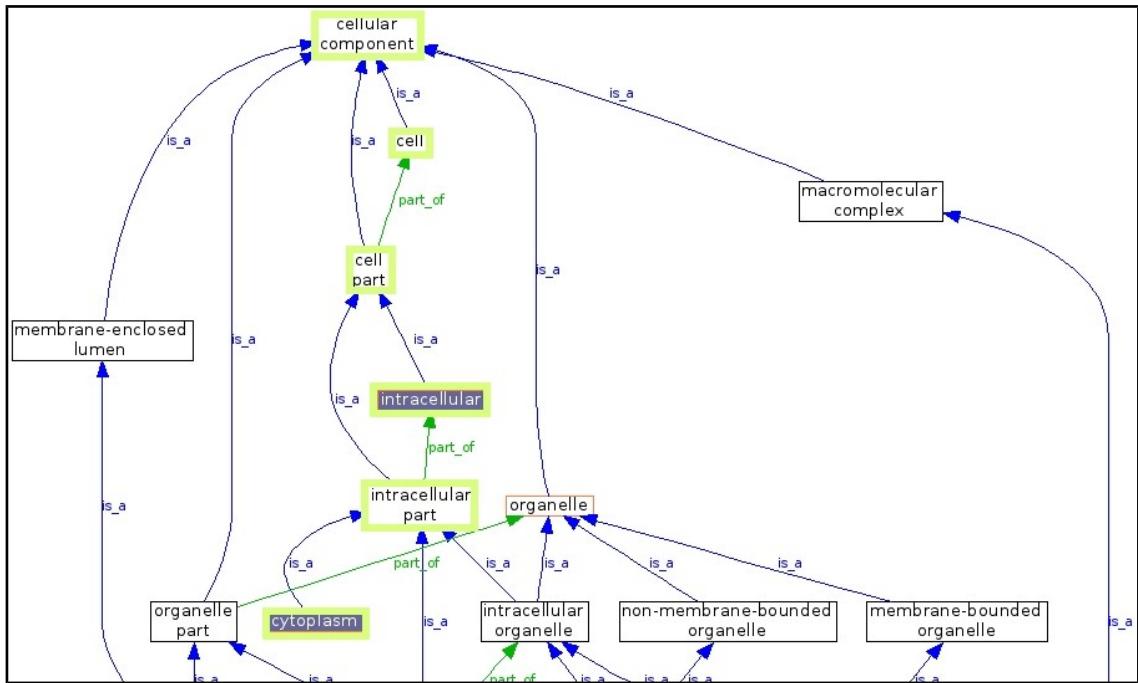
Considering a small portion of the **molecular function** graph, going from most specific to least specific.



The protein in question is considered to be:

DNA binding which implies it is_a nucleic acid binding protein so it is_a heterocyclic compound binding & organic cyclic compound binding protein and thus is_a binding protein which is_a molecular function

Similarly for the **cellular component** graph.



The protein in question is considered to be a:

component of the **cytoplasm** which implies it ***is_a***
component of an **intracellular part** which implies it ***is_an***
intracellular component which implies it ***is_a*** component of a **cell part** which implies it ***is_a***
cell component which implies it ***is_a*** cellular component

In a very similar fashion you could follow a path or two through the **biological process** maze. This one is too scary for me folks, you are on your own!

Where do each of the SMART domains start and end?

Do the regions match your earlier recording? If not, why not?

SMART predicts a **Paired_dom** from amino acid positions **4 → 142**.

| | | | | |
|-------|---|-----|------------|-------------------------|
| Smart | 4 | 142 | Paired_dom | SM00351 |
|-------|---|-----|------------|-------------------------|

Previously you noted that UniProtKB claims a **Paired** domain extending from residues **4 → 130**.

| | | | |
|---------------------|---------|-----|--------|
| Domain ⁱ | 4 → 130 | 127 | Paired |
|---------------------|---------|-----|--------|

SMART predicts a **Homeodomain** from amino acid positions **224 → 286**.

| | | | | |
|-------|-----|-----|-------------|-------------------------|
| Smart | 224 | 286 | Homeodomain | SM00389 |
|-------|-----|-----|-------------|-------------------------|

Previously you noted that UniProtKB predicts a **Homeobox** extending from residues **210 → 269**.

| | | | |
|--------------------------|-----------|----|----------|
| DNA binding ⁱ | 210 – 269 | 60 | Homeobox |
|--------------------------|-----------|----|----------|

So no agreement in nomenclature or position. It would be nice if we could all agree what to call things, but I suppose that is not likely to happen in this world of personalised whimsy. There is more justification for the variation in predicted position of the various domains.

SMART and UniProtKB will be using marginally different methods and models to predict domains. It is exceedingly good news that there is pretty comprehensive agreement as to which domains present and roughly where they are. However, it would be unreasonable to expect differing prediction strategies to come up with precisely the same answers, correct to the amino acid position. After all, I wonder if any two human experts would exactly agree where a particular feature began and ended, even given all possible evidence?

What are the Interpro database identifiers for the two major PAX6 domains?

Why does Prints appear to predict four Paired_doms?

There are three independent predictions (from **Prosite_profiles**, **Smart** & **Pfam**) of a **Homeobox_dom**. Each and all suggest that this protein belongs to the **Homeobox_dom Interpro** family which has the **Accession** number **IPR001356**.

| | | | | | |
|------------------|-----|-----|-------------|-------------------------|---------------------------|
| Prosite_profiles | 222 | 282 | Homeodomain | PS50071 | IPR001356 |
| Smart | 224 | 286 | Homeodomain | SM00389 | IPR001356 |
| Pfam | 226 | 281 | Homeodomain | PF00046 | IPR001356 |

There are four independent predictions (from **Prosite_profiles**, **Smart** **Pfam** & **Prints**) of a **Paired_dom**. Each and all suggest that this protein belongs to the **Paired_dom Interpro** family which has the **Accession** number **IPR001523**.

| | | | | | |
|------------------|----|-----|------------|-------------------------|---------------------------|
| Pfam | 4 | 142 | Paired_dom | PF00292 | IPR001523 |
| Smart | 4 | 142 | Paired_dom | SM00351 | IPR001523 |
| Prosite_profiles | 4 | 144 | Paired_dom | PS51057 | IPR001523 |
| Prints | 8 | 23 | Paired_dom | PR00027 | IPR001523 |
| Prints | 26 | 44 | Paired_dom | PR00027 | IPR001523 |
| Prints | 60 | 77 | Paired_dom | PR00027 | IPR001523 |
| Prints | 78 | 95 | Paired_dom | PR00027 | IPR001523 |

Ensembl no longer use the **Prosite patterns** to seek domains here as they consider too many false positives are generated. Had they been used, they would have detected the **Homeobox_dom**, but not the **Paired_dom** as this is an **isoform 5a PAX6** protein. The **Prosite pattern** for **Paired_dom** will be broken by the **14** amino acid insertion of **isoform 5a** (see previous discussion).

Prints does not find the **Homeobox_dom**. You already will be aware this search fails from looking at the UniProtKB predictions.

Prints appears to find **FOUR Paired_doms**. Of course, this is only because of the way Prints works. Prints finds **FOUR** signatures that together indicate **ONE Paired_dom**. I think we might have been here before? Possibly too many times.

Which domain, **Paired_dom** or **Homeobox_dom** is more common in humans?

How many human **PAX** genes are there?

As you will have expected, there are but **9 Paired_doms** in the Human genome. There are many more **Homeobox_doms**.

Are all the PAX genes on Chromosome 11?

Of course not? What a stupid question!

Well, I suppose they could all be on **Chromosome 11**? By chance ... or maybe design ... who knows, the lack of predictable pattern in all this business never ceases to astound me.

But, philosophy aside, the answer is **NO**.

How does Interpro match with the PAX6 Paralogues reported by Ensembl/GeneCards earlier?

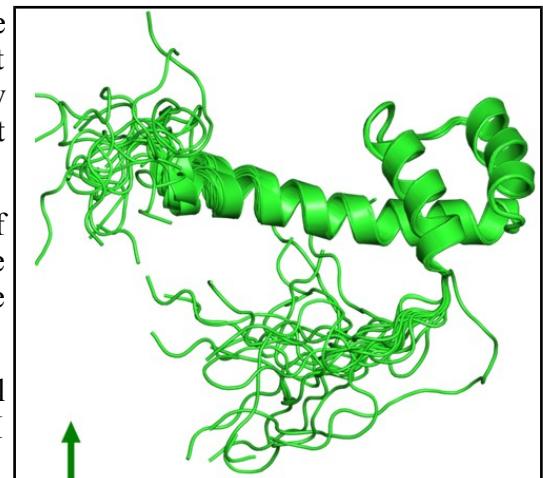
The evidence from both **GeneCards** and **Ensembl** is that there are **9 PAX** paralogues in Human. Yep, we all agree and ... these questions are becoming a trifle repetitive one feels!

Can you explain the strangely frayed ends displayed in some of the representations of the **2cue** 3D structure?

2cue is a 3D structure determined by Nuclear Magnetic Resonance (**NMR**). This is a process that does not involve immobilizing the target as a crystal (as is the case with structures determined by **X-ray crystallography**). Parts of the protein will still be moving around whilst its structure is being determined.

I think of **NMR** as analogous to taking a long exposure photograph of a group of children. Each child will appear in many different places! The frayed ends represent various positions in which the ends of the **homeobox** were detected during the **NMR** process.

In some views, including the one you were offered to move around, all the possible positions are averaged out before the structure is stored. I prefer the fuzzy view ... much more fun.



I broadly believe that which I have just typed, however, I must stress that my understanding of **NMR** is tragically incomplete. If anyone would like to offer a better explanation, I am very willing to hear it.

From your investigations comparing mRNA/cDNA with genomic DNA:

What is the amino acid corresponding to this position in the mRNA of the aniridia patient?

| |
|---|
| R Q K I V E L P H S G A R P C |
| GGCAGAAGATTGTAGAGCTACCTCACAGCGGGGCCGGCCGTGC |
| |
| GGCAGAAGATTGTAGAGCTAGCTCACAGCGGGGCCGGCCGTGC |

This is easy to answer. The top sequence is the mRNA from the **aniridia** patient. **spline** is kind enough to explicitly inform us that the mutated codon, CCT, will be expressed a Proline.

So, why not translate the wild type genomic sequence also **spline**?! Easy enough to look up. But I resent having to do so!

From your investigations of Local Alignment:

How might the gap around **24,600** in the genomic sequence been positioned more intelligently?

spin has positioned a gap in this region merely to maximize the overall alignment score. There is more than one way of achieving this simple goal. However, if it were to be recognized that the gap to be positioned was to represent an intron, then one of the arithmetically equivalent options becomes far more attractive than the others. This “best” option is not the one chosen by **spin**, which is forgiveable as **spin** had nor reason to expect an intron and was not written to understand the properties of introns anyway.

The alignment chosen for this region by **spin** was:

| 24392 | 24402 | 24412 | 24422 | 24432 | 24442 |
|--------------|--------------------------------------|------------------------------|-------|-------|-------|
| pax6-genomic | CTAGCAGCCAAAATAGATCTACCTGAAGCAAGAATA | CAGGTACCGAGAGACTGTGCAGTT | | | |
| | | | | | |
| pax6-cDNA | ctagcagccaaaatagatctacctgaagcaagaata | caggtacggagactgtgcagtt | | | |
| 1144 | 1154 | 1164 | 1174 | 1184 | - |
| | ... | | | | |
| 24632 | 24642 | 24652 | 24662 | 24672 | 24682 |
| pax6-genomic | GTGCTAACCTGTCCCACCTGATTCCAGGTATGGTTT | CTAATCGAAGGGCCAATGGAG | | | |
| | | | | | |
| pax6-cDNA | | tggtttctaatcgaaagggccaatggag | | | |
| - | - | - | - | 1195 | 1205 |

Shifting the gap 3 places to the left neither changes the size of the gap nor the perfection of the alignment either side of the gap and so does not affect the alignment score. However, it does mean the gap begins with an **GT** and ends with a **AG** which is what one might expect if it were known that the gap represented an intron. So, if **spin** was a little better informed, the improved alignment would have been:

| 24392 | 24402 | 24412 | 24422 | 24432 | 24442 |
|--------------|--------------------------------------|---------------------------------|-------|-------|-------|
| pax6-genomic | CTAGCAGCCAAAATAGATCTACCTGAAGCAAGAATA | CAGGTACCGAGAGACTGTGCAGTT | | | |
| | | | | | |
| pax6-cDNA | ctagcagccaaaatagatctacctgaagcaagaata | caggtacggagactgtgcagtt | | | |
| 1144 | 1154 | 1164 | 1174 | 1184 | - |
| | ... | | | | |
| 24632 | 24642 | 24652 | 24662 | 24672 | 24682 |
| pax6-genomic | GTGCTAACCTGTCCCACCTGATTCCAGGTATGGTTT | CTAATCGAAGGGCCAATGGAG | | | |
| | | | | | |
| pax6-cDNA | | gtatggtttctaatcgaaagggccaatggag | | | |
| - | - | - | - | 1195 | 1205 |

This is the alignment that the customized program **splign** would have chosen as **splign** understands something of the expected properties of introns. **spin** was confused because it is a general alignment program concerned only with the simple arithmetic of alignment scores.

Why do you suppose your aligned exons are not presented in the correct positional order?

To **spin**, the logical order in which to present the alignments is that governed by quality rather than position. So, the highest scoring alignment, rather than the first exon alignment, will be at the top of the list. I think this is generally logical. Once again, the program **splign**, knowing it was looking for an ordered set of exons, was more obliging.

From your investigations of ORF detection:

At what base position does the coding sequence of the mRNA commence?

From the illustration in the notes above, it can be determined (with a bit of pain filled arithmetic) that the A base of the **ATG Methionine** codon that starts the coding region of this mRNA is at position **418**.

Note that the nearest **Stop Codon** before the **Methionine** is well before the start of the ORF indicated by **plotorf**. This shows that the definition of an ORF being used by **plotorf** is **Start → Stop**, rather than **Stop → Stop**. As you can see from the output below (generated by another **Emboss** program called **showorf**).

```
-----|-----|-----|-----|-----|
301 TAActaggggcgcgagatgtgtgaggctttattgtgagagtggacag 350
F1    1 * L G A R R C V R P F I V R V D R 16
-----|-----|-----|-----|-----|
351 acatccgagatttcagagccccatattcgagcccggtggaatcccgccgc 400
F1    17 H P R F Q S P I F E P R G I P R P 33
-----|-----|-----|-----|-----|
401 ccccagccagagccagcATGcagaacagtcacagcggagtgaatcagctc 450
F1    34 P A R A S M Q N S H S G V N Q L 49
```

What is the base position of the last base of the coding sequence?

Slide along the sequence display and you should be able to conform the coding region of this mRNA ends at position **1683**. To complete the dreadful pedantic excess, I support his with more **showorf** output.

```
-----|-----|-----|-----|-----|
1651 cctgatatgtctcaatactggccaagattacagTAAaaaaaaaaaaa 1698
F1    450 P D M S Q Y W P R L Q * K K K K 4
```

Leaving only the mystery of what **showorf** might be trying to convey by the “**4**” at the end of the display? I find my concern drifting somewhat.

What is the single amino acid difference between the two sequences?

It has been established that there is but one base pair difference in the coding region of this cDNA and the wild type genomic sequence. There can therefore be, at most, one amino acid that is different between the two protein sequences. Surely a case for a global rather than a local alignment strategy? Not that the choice should be of any real consequence with sequences that are this similar.

| | | | | | |
|-------------------------|---|-------------|----|----|----|
| 1 | 11 | 21 | 31 | 41 | 51 |
| sp P26367 PAX6_H | MQNSHSGVNQLGGVFVNNGRPLPDSTRQKIVELAHSGARPCDISRILQVSNGCVSKILGRY | *****:***** | | | |
| pax6 | MQNSHSGVNQLGGVFVNNGRPLPDSTRQKIVELPHSGARPCDISRILQVSNGCVSKILGRY | | | | |
| 1 | 11 | 21 | 31 | 41 | 51 |

From the alignment I generated with the global option of **spin**, there is a **A → P** (**Alanine → Proline**) substitution evident. **Alanine** and **Proline** are amino acids with quite different properties, so it is reasonable to suppose that the this substitution will be significant.

What is the position of the difference?

The substitution is at residue **33**, as you will have seen reported by various sources previously.

From your investigations of Restriction Mapping

There are quite a few less enzymes mentioned in the map you have just made compared to that generated by remap. Can you speculate what the main reason for this might be?

Probably differences in the definition of a **6** cutter.

E.g. **BfuAI** has a recognition site of **ACCTGCNNNN_NNNN-**, is this a **6** base pair recognition site or **14**?

Enzymes in remap maps but not reported by nebcutter include:

| | |
|--|---|
| SfeI | CfrI |
| Type II restriction enzyme
subtype: P | Type II restriction enzyme
subtype: P |
| Recognition Sequence: help?
C ^A TRYAG | Recognition Sequence: help?
Y ^A GCCR |
| | |

6 cutters according to **remap**? Surely **R** & **Y** only count **0.5**? I agree with **nebcutter**, these are **5 cutters**.

| |
|--|
| Cac8I |
| Type II restriction enzyme
subtype: P |
| Recognition Sequence: help?
GCN ^A NGC |
| |

Oh come on **remap**!! you cannot count Ns!! This is a **5 cutter** also.

Some enzymes in this map appear in the same place as **remap** predicted, but have different names. Can you explain why?

Restriction mapping programs, by default, only map one member of each **isoschizomer** family. There is no consistency between programs in the choice of the representative enzyme.

For example:

| | | | | |
|--|-----|-----|------------------------|--------------------|
| Commercially Available: | | | | |
| Enzymes Cloned Sequenced Recognition Sequence Suppliers | | | | |
| BseX3I | - | - | CGGCCG | IV |
| BstZI | - | - | CGGCCG | R |
| EagI | yes | yes | CGGCCG | N |
| EclXI | - | - | CGGCCG | MS |
| Eco52I | - | - | CGGCCG | FK |
| Count: 5 | | | | |
| Not Commercially Available: | | | | |
| Enzymes Cloned Sequenced Recognition Sequence | | | | |
| AaaI | - | - | CGGCCG | |
| BsODI | - | - | CGGCCG | |
| SenPT16I | - | - | CGGCCG | |
| TauII | - | - | CGGCCG | |
| Tsp504I | - | - | CGGCCG | |
| XmaIII | - | - | CGGCCG | |
| Count: 6 | | | | |

remap chooses to show just **XmaIII**

nebcutter chooses **EagI**, probably because it is commercially available.

They both have the same recognition site and so would both cut at the indicated position.

From your investigations of Searching for sequence similarities in databases

When would **Mask lower case letters** be a useful thing to do?

Generally, whenever one might suspect the automatic masking algorithms of **blast** might miss a non informative region in a specific query sequence, obviously.

A specific example might be when a query sequence contained a significant informative region that was known to be common amongst the sequences being searched. If this region was left unmasked, **blast** would pick up so many similar matches to this one region that other interesting similarities might be obscured. By manually masking such a region by changing it to lower case, its matches would not be seen by **blast** and matches with other regions of the query sequence should be more apparent.

Which parameters would **blast** need to **automatically adjust** to cater for short input sequences (such as primers being tested for uniqueness), and why?

The **word size**: Clearly, if you are trying to find matches for a primer (for example) of around **20** base pairs, it would be pretty silly to use a **word size of 28** (default for **megablast**). A **word** the same size as the primer would find only exact matches. A **word** of about **7** would allow a couple of mismatches and would probably be most generally appropriate.

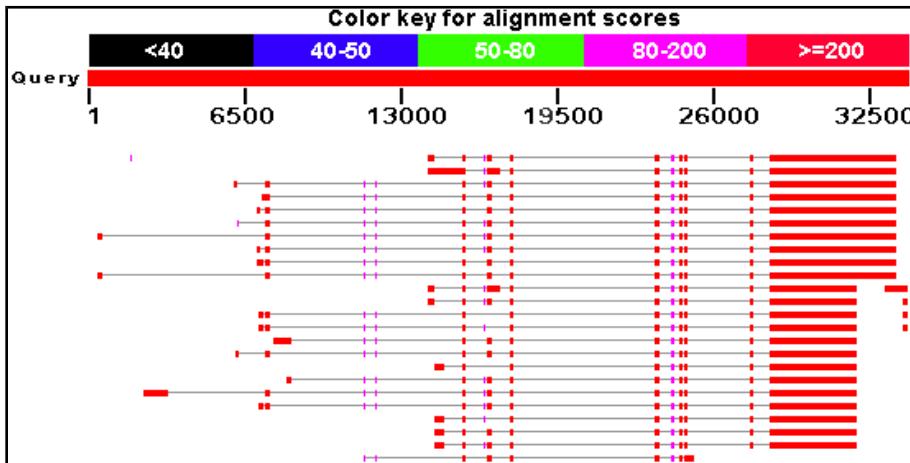
The **expect score**: As good chance matches between a short query sequence and a large database will be abundant, it would not be sensible to choose a demanding (i.e. small) **expect score** to represent the limit of significance. In particular, a primer sized query sequence of around **20** base pairs might easily exactly match more than **10** times (generally the default maximum expect score for a significant match) just by chance. After all, there are only **4** bases, a string of **20** is not that long and the databases can be huge! Typically **blast** chooses very high **expect score** cut off for short query sequences, effectively removing the **expect score** filter altogether.

Why do you suppose that a few of the exons do not achieve the maximum score?

Summary:

In common with most database searching programs, **blast** compares query sequences with database entries using a local strategy. The overall evaluation of a particular match is computed from the local scores computed for all matched local regions.

Individual regional matches are coloured according quality. In this query, all true matches should be perfect, or nearly so. Scores might therefore be expected to be maximal (≥ 200). However, they are not? Some only manage a score in the range **80-200**.



The score referenced for this purpose is the **bit score**. For a full, no holds barred definition of this score, try [here](#). I prefer this somewhat gentler version:

“The **bit score** gives an indication of how good the alignment is; the higher the score, the better the alignment. In general terms, this score is calculated from a formula that takes into account the alignment of similar or identical residues, as well as any gaps introduced to align the sequences. A key element in this calculation is the “substitution matrix”, which assigns a score for aligning any possible pair of residues. The **BLOSUM62** matrix is the default for most **BLAST** programs, the exceptions being **blastn** and **MegaBLAST** (programs that perform **nucleotide–nucleotide** comparisons and hence do not use protein-specific matrices). Bit scores are normalized, which means that the bit scores from different alignments can be compared, even if different scoring matrices have been used.”

Still too scary? The important things to note are that:

- These scores are based on a simple DNA scoring matrix (probably **1** for a match, **0** for a mismatch). So the scores must be limited by the length of the alignment.
- The scores reflect penalties for **indels** (insertions or deletions).
- Very cleverly, the scores are normalised so that they do not depend on the chosen scoring matrix. This allows bits scores from searches using different scoring matrices to be compared.

This being so, **bit scores** will reflect the length of an alignment as well as its quality. If an alignment is very short, it might be perfect but still not achieve a very high value. **bit scores** are designed to reflect significance, not just local quality. A short perfect match clearly can be less significant than a longer less perfect match. That is what you see illustrated here.

Full Answer:

You can see evidence of what is occurring in the alignments further down your results. Here is illustrated one of the **80-200** exons that occur in all transcripts at position **23,346**¹⁴⁸. The match is perfect, but the length of the exon is consistently just to short to get to the heady **>=200** level.

Note how imperfectly **blast** finds exon/intron boundaries. If the start of an intron happens to match the start of the next exon, **blast** will include the bases in two alignments¹⁴⁹. It is not looking for exons and introns as was **spline**, it just mindlessly seeks matches.

| Range 7: 999 to 1086 GenBank Graphics | | | | | ▼ Next Match | ▲ Previous Match | ▲ First Match |
|---------------------------------------|--|-------------|----------|-----------|--------------|------------------|---------------|
| Score | Expect | Identities | Gaps | Strand | | | |
| 163 bits(88) | 8e-37 | 88/88(100%) | 0/88(0%) | Plus/Plus | | | |
| Query 24346 | AGAGTTGAGAGAACCCATTATCCAGATGTGTTGCCGAGAAAGACTAGCAGCCAAAT | | | | 24405 | | |
| Sbjct 999 | AGAGTTGAGAGAACCCATTATCCAGATGTGTTGCCGAGAAAGACTAGCAGCCAAAT | | | | | 1058 | |
| Query 24406 | AGATCTACCTGAAAGCAAAATACAGGT | | | | 24433 | | |
| Sbjct 1059 | AGATCTACCTGAAAGCAAAATACAGGT | | | | | 1086 | |

| Range 8: 1081 to 1234 GenBank Graphics | | | | | ▼ Next Match | ▲ Previous Match | ▲ First Match |
|--|--|---------------|-----------|-----------|--------------|------------------|---------------|
| Score | Expect | Identities | Gaps | Strand | | | |
| 285 bits(154) | 2e-73 | 154/154(100%) | 0/154(0%) | Plus/Plus | | | |
| Query 24657 | CAGGTATGGTTCTTAATCGAAGGCCAAATGGAGAGAGAAAACGTGAGGAATCAG | | | | 24716 | | |
| Sbjct 1081 | CAGGTATGGTTCTTAATCGAAGGCCAAATGGAGAGAGAAAACGTGAGGAATCAG | | | | | 1140 | |
| Query 24717 | AGAACGACAGGCCAGCAACACACCTAGTCATACTTCTCTAGCAGTAGTTTCAGCACCACT | | | | 24776 | | |
| Sbjct 1141 | AGAACGACAGGCCAGCAACACACCTAGTCATACTTCTCTAGCAGTAGTTTCAGCACCACT | | | | | 1200 | |
| Query 24777 | GTCTACCAACCAATTCCACACCCACCCACCGG | | | | 24810 | | |
| Sbjct 1201 | GTCTACCAACCAATTCCACACCCACCCACCGG | | | | | 1234 | |

| Range 9: 1234 to 1350 GenBank Graphics | | | | | ▼ Next Match | ▲ Previous Match | ▲ First Match |
|--|--|---------------|-----------|-----------|--------------|------------------|---------------|
| Score | Expect | Identities | Gaps | Strand | | | |
| 217 bits(117) | 6e-53 | 117/117(100%) | 0/117(0%) | Plus/Plus | | | |
| Query 24908 | GTTTCCCTCTCACATCTGGCTCATGTTGGGCCGAACAGACACAGCCCTCACAAACACC | | | | 24967 | | |
| Sbjct 1234 | GTTTCCCTCTCACATCTGGCTCATGTTGGGCCGAACAGACACAGCCCTCACAAACACC | | | | | 1293 | |
| Query 24968 | TACAGCGCTCTGCCCTATGCCAGCTTACCATGGCAAATAACCTGCCTATGCAA | | | | 25024 | | |
| Sbjct 1294 | TACAGCGCTCTGCCCTATGCCAGCTTACCATGGCAAATAACCTGCCTATGCAA | | | | | 1350 | |

¹⁴⁸ In order to make this illustration, I needed set Sort by: (top of the alignments) to Query start position.

| | |
|---|--|
| Query 15745 CCCGAATTCTGCAG 15758 | Sbjct 404 CCCGAATTCTGCAG 417 |
| Range 3: 416 to 461 GenBank Graphics | |
| Score 86.1 bits(46) | Expect 2e-13 Identities 46/46(100%) Gaps 0/46(0%) Strand Plus/Plus |
| Query 16548 AGACCCATGCAGATGCAAAAGTCCAAGTGGTGGACAATCAAACGT 16593 | |
| Sbjct 416 | AGACCCATGCAGATGCAAAAGTCCAAGTGGTGGACAATCAAACGT 461 |
| Range 4: 460 to 677 GenBank Graphics | |
| Score 403 bits(218) | Expect 5e-109 Identities 218/218(100%) Gaps 0/218(0%) Strand Plus/Plus |
| Query 16686 | GTTGCCAACCGGATGTGAGTAAAATTCTGGCAGGTATTACGAGACTGGCTCATCGA 16745 |
| Sbjct 460 | GTTGCCAACCGGATGTGAGTAAAATTCTGGCAGGTATTACGAGACTGGCTCATCGA 519 |

For a further example, look at the exon that is found only in the **isoform 5a** transcripts. It is tiny (**42** base pairs) and scores well below **>=200** even though it is a perfect match.

Note that the alignment is **46** base pairs long due to **blast** adding on two bases either side that are actually the highly conserved intron start and end base pairs. As you can see, these extra base pairs occur in the preceding and succeeding alignment also.

Explain why one exon in the reasonably consistent region, does not appear in all of the transcript matches?

Oh dear oh dear! Not this again.

Well I refer to the isoform 5a exon, of course. One day I will tidy these questions up a trifle!

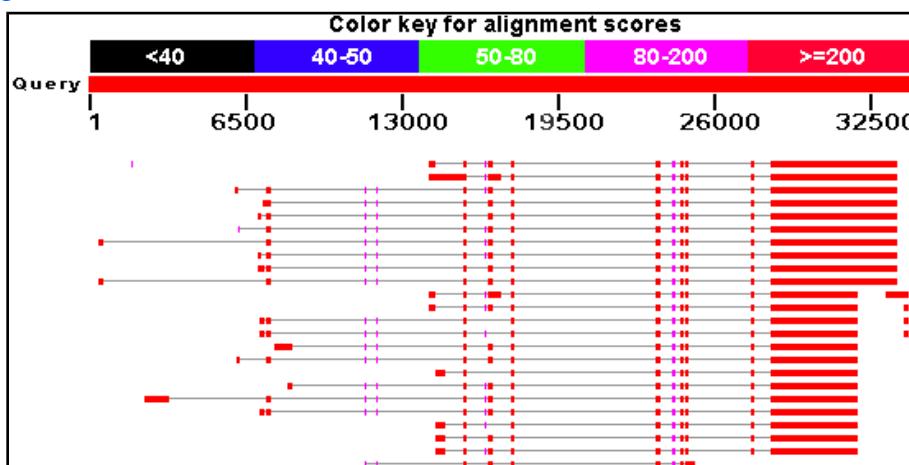
Why were you not surprised to discover **24 PAX6** transcripts in **Refseq** matching this sequence?

Well, the story has got quite a bit more complicated since I first asked this question. I now pretty much answer it in the instruction text. However, never one to miss an opportunity to repeat myself. The answer is (or at least it will be once **GeneCards** catches up!):

Because **GeneCards** says there should be **11** quality and a further **13** less supported **PAX6 mRNA** sequences in **RefSeq**. A total of **24 PAX6 implied transcripts** in total.

Which of the **Refseq PAX6** transcripts corresponds to **isoform 5a**?

The **isoform 5a** transcripts can be spotted most easily from the graphic. They are the ones with the extra small exon slightly to the left of middle (around base position **1,600**). For example, the **first, second** and **third blast** matches displayed. If you hover over these matches with your mouse, you will see that they are **transcript variants 11, 10 and 8** (in the order of the graphic).



In what circumstances would you imagine that the **Max matches in a query range** parameter might be set to something other than its default value of **0**?

The default value for this parameter, **0**, means that there be no limit to the number of matches listed with any given region of the query sequence. This can mislead when one region is prolifically and strongly conserved in the database being searched. In such a case, it is possible that so many matches with one region are found that there is not space in the list of hits for other, weaker but significant, matches with other regions of the query sequence.

This option allows a user to say:

“Once you have found **50** (say) similar matches with a single part of my query, I **have got the message!!**, list no more matches unless they pertain to a different part of my query and thus tell me something new.”

All this you can convey by just changing that **0** to **50!!** Are not computers wonderful?

149 6 base pairs (Sbjct: 1081-1086, CAGGTa) occur in both the first two matches illustrated. Just 1 base pair is shared between the 2nd and 3rd match (Sbjct: 1234, G).

What are the 9 stronger matches around base position 16,000?

Matches between the regions of genomic DNA encoding **Paired Box** domains.

Why would you expect exactly 9 matches around this point?

Because there are how many **Paired box** domains are suggested to be in the human genome by counting the number of quality **mRNA** sequences in **RefSeq** claiming to include a **Paired box** coding region. There is **PAX6** plus its **8** paralogues, imaginatively all named:

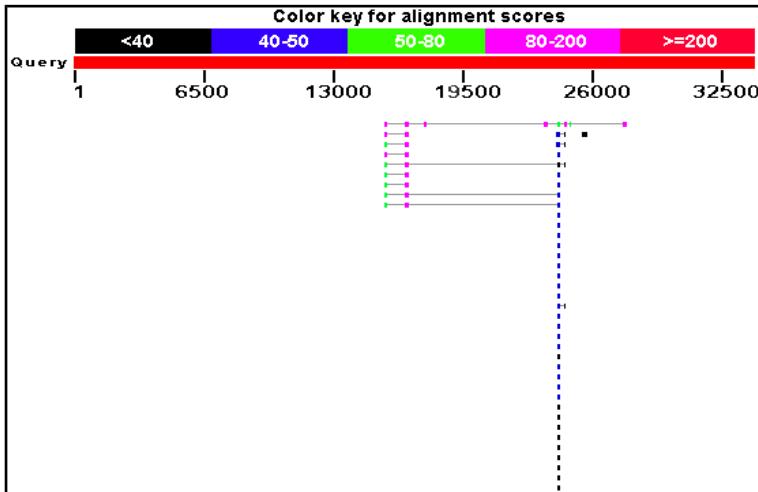
PAX1, PAX2, PAX3, PAX4, PAX5, PAX6, PAX7, PAX8 & PAX9

What do you make of the plethora of matches around 24,000?

These are matches between human **mRNA** sequences with the regions of genomic DNA encoding **Homeo Box** domains. As you discovered from **Interpro**, there are many of these.

The thin line joining features implies that those features relate to the same database entry.

Notice that **4** of the **9** proteins matching a **Paired box** genomic region also match a **Homeo box** region. the remaining **5** do not. This implies that **4** of the **9** proteins corresponding to the hits detected here have a **Paired box** domain near the start of the protein and a **Homeo box** domain further along. This is exactly as was suggested by the **PROSITE** annotation you examined.



Why do you suppose the **Paired box** matches precede the **Homeobox** matches?

Because they score more highly and so, in the opinion of **blast**, are more worthy. Primarily, they score more highly because they are longer. The list is ranked by **E Value**. Good matches with long sequence are less likely to occur by chance than equally good matches with shorter sequences.

How do you suppose the **Max matches in a query range** parameter might be of value if this order was reversed?

If **Paired boxes** had been more prolific, then the number of **Paired box** matches might have filled the **blast** hit list before the highest scoring **Homeo box** hit was registered.

If **Homeo boxes** were longer, and so justified a better **E value**, then the number of **Homeo box** matches might have filled the **blast** hit list before the highest scoring **Paired box** hit was registered.

Either of these situations would be very unfortunate, but easily avoided by setting the **Max matches in a query range** parameter to something sensible (**50** say). This would ensure that only the top **50** items in the **blast** hit list would be dominated by the strongest hit.

For further discussion of the parameter, see above.

How does this “non-informative” region match expectations suggested by **Prosite** and the **Feature table of Uniprot** for **PAX6_HUMAN**?

blast identifies two non-informative regions. I only discussed the prettiest one above. The region discussed is comprised largely of **Serines, Prolines, Threonines & Isoleucines** the **15** residues between **294-308**.

| Score | Expect | Method | Identities | Positives | Gaps | Frame |
|----------------|--|------------------------------|-------------|------------|----------|-------|
| 81.3 bits(199) | 5e-29 | Compositional matrix adjust. | 51/52(98%) | 51/52(98%) | 0/52(0%) | +3 |
| Query 24654 | FQWFSNRRAKWRREEKLRNQRRQASN | pshipi sssfsts | NYQPIPQPTTP | 24809 | | |
| Sbjct 254 | IOWWFSNRRAKWRREEKLRNQRRQASNTPSHIPISSSFSTSYYQPIPQPTTP | | | 305 | | |

The second (to be found much further down your **blast Alignments** output) is comprised entirely of **Arginines, Luecines and Lysines and Glutamines**, the **10** residues between **203 - 212**.

| Score | Expect | Method | Identities | Positives | Gaps | Frame |
|----------------|--|------------------------------|------------|------------|----------|-------|
| 85.9 bits(211) | 3e-16 | Compositional matrix adjust. | 56/66(85%) | 58/66(87%) | 5/66(7%) | +3 |
| Query 23649 | YHPILFVP-----DGCQQQEGGGENTNSISSNGEDSDEAQ | MrlqlkrkIg l | NRTSFTQEQ | 23813 | | |
| Sbjct 162 | ++P VP DGCQQQEGGGENTNSISSNGEDSDEAQMRQLQKRKLQRNRTSFTQEQ | | | | | |
| Query 23814 | IEALEK 23831 | | | | | |
| Sbjct 222 | IEALEK 227 | | | | | |

Uniprotkb also suggests there are two **compositionally biased regions**.

| | | | |
|--------------------|-----------|-----|------------------|
| Compositional bias | 131 – 209 | 79 | Gln/Gly-rich |
| Compositional bias | 279 – 422 | 144 | Pro/Ser/Thr-rich |

Well, hardly an exact match, but there is approximate agreement? One would certainly suppose that **blast** is only willing to mask fairly severe cases of **compositional bias**. It is also probable that **blast** has a rather more mechanistic (i.e. non-biological) interpretation of what **computational bias** is?

PROSITE also predicts the more obvious region of **computational bias**, rather more generally:

“An octapeptide and/or a homeodomain can occur C-terminal to the paired domain, as well as a Pro-Ser-Thr-rich C-terminus”

From your investigations of Primer Design

Do you think **10** primer pair suggestions is sufficient? If not, what number would you choose?

Until very recently, the default here was **5**. That seemed rather low to me. I included this question to solicit opinion rather than to impart knowledge. A default of **10** seems more in line with my instincts, but people who use this program seriously mostly tell me that they can select suitable primers from the first **2** or **3** suggestions of the program. So, **5** would seem a good choice and **10** would be moving towards cautiously overdoing things.

On the whole, informed opinion suggests that **10** suggestions will be more than enough in most circumstances.

What value would you choose here if you were looking for uncluttered results?

Summary:

Clearly, the smaller the number chosen, the shorter will be the list of spurious products. However, pick something too small and you risk including unintended product(s) that could cause confusion. The size selected must be sufficient that larger unwanted PCR product(s) could easily be spotted by other means (simply by size?).

Full Answer:

Well, mostly for me, and just in case you were curious, when I first wrote the question, the parameter was very different and not so easy to understand. Pure self indulgence, I know, but here is the history. The parameter explained itself, via the  button, thus:



I interpreted this to mean that only **blast** predicted products of up to **X+4,000** base pairs, where **X** base pairs is the length of the intended target, will be given any regard. It is thus assumed that a difference of **4,000** base pairs between an intended PCR product (predicted by **primer3**) and a spurious product (detected by **blast**) can easily be detected simply by size difference.

Of course this parameter also will reject unwanted **blast** predicted products that are less than **Y-4,000** base pairs, where **Y** base pairs is the length of the intended target, will be given any regard. Given the largest possible **primer3** suggestion will be **1,000** base pairs (the form setting for the exercise specifies products of between **100¹⁵⁰** and **1,000** base pairs), this is hardly an issue here.

Comment upon the small default value for the Blast word size?

By default, **blast** will be looking for aligned exactly matching blocks of **7** nucleotides when identifying where a primer might match a database entry. The entire primer match with the template sequence does not have to be exact for the primer to be acceptable. The entire primer is typically only around **20** bases long. And word size much more than **7** would clearly miss too much to be effective.

¹⁵⁰ The form explicitly declares a minimum of **70**, but the ranges from which the **forward & reverse** primers must come (**15000-15700** & **15800-16500**) make the smallest possible **primer3** prediction **100** base pairs long.

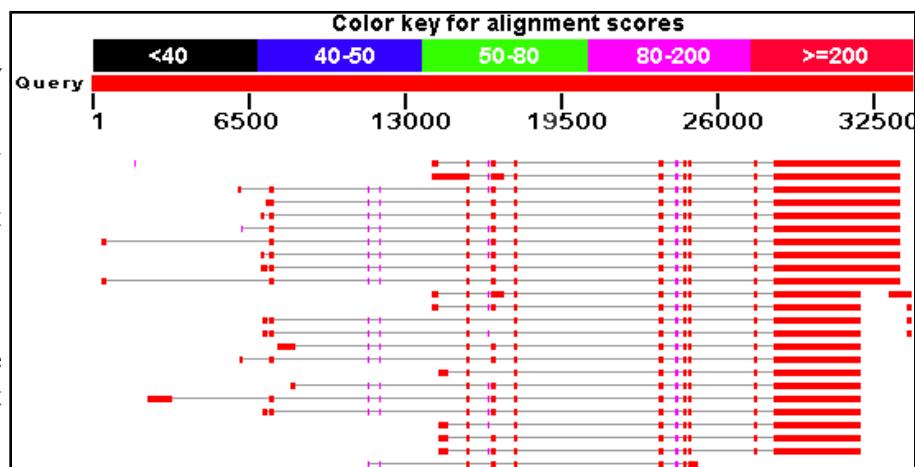
Why do you suppose **blast** did not pick up all the transcripts?

Summary:

Well, the simple answer is that the **PREDICTED** transcripts that were not detected as unwanted products cannot include either the forward primer, or the reverse primer, or both. This is, almost, the only possible explanation.

Full Answer:

Of course, for this run, you did specify that you were not interested in products longer than **4,000** base pairs, so it could be that one or more products were possible but longer than that? I suspect this would only be feasible if there were retained introns involved, but previous **blast** results do no suggest this to be the case. I would say the only possible candidate for an over-length product might be the second hit down in the graphical representation generated previously by **blast**. The first and third exons from the left look a bit bloated, but not really sufficiently to cause a problem.



I might also be that unwanted PCR products are eliminated/introduced due to variations in the predicted transcripts. However, this can be ruled out as previous experiments, **blast** assures us that all **24** potential transcripts match the genomic sequence exactly.

Enough! Only because I want to, I will compute the alignments to prove the missing primer matches. Read no further unless you are truly in the mood. Much of the reason for recording the rest of this answer is that, apart from enjoying the pursuit of irrelevant detail, I also wanted to remember how I made the alignments and certainly feel I could have made both these, and my point much more simply? Suggestions welcome.

| Description | Max score | Total score | Query cover | E value | Ident | Accession |
|--|-----------|-------------|-------------|---------|-------|----------------|
| Homo sapiens paired box 6 (PAX6), transcript variant 11, mRNA | 9659 | 12484 | 19% | 0.0 | 100% | NM_001310161_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 10, mRNA | 9659 | 15161 | 24% | 0.0 | 100% | NM_001310160_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 8, mRNA | 9659 | 12929 | 20% | 0.0 | 100% | NM_001310158_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 7, mRNA | 9659 | 12729 | 20% | 0.0 | 100% | NM_001258465_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 6, mRNA | 9659 | 12761 | 20% | 0.0 | 100% | NM_001258464_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 5, mRNA | 9659 | 12737 | 20% | 0.0 | 100% | NM_001258463_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 4, mRNA | 9659 | 12862 | 20% | 0.0 | 100% | NM_001258462_1 |
| Homo sapiens paired box 6 (PAX6), transcript variant 2, mRNA | 9659 | 12833 | 20% | 0.0 | 100% | NM_001604_5 |
| Homo sapiens paired box 6 (PAX6), transcript variant 1, mRNA | 9659 | 12942 | 20% | 0.0 | 100% | NM_000280_4 |
| Homo sapiens paired box 6 (PAX6), transcript variant 3, mRNA | 9659 | 12791 | 20% | 0.0 | 100% | NM_00127612_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X13, mRNA | 6613 | 10063 | 15% | 0.0 | 100% | XM_005252958_3 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X12, mRNA | 6613 | 9439 | 14% | 0.0 | 100% | XM_011520153_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X11, mRNA | 6613 | 9329 | 14% | 0.0 | 100% | XM_006718246_2 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X10, mRNA | 6613 | 9410 | 14% | 0.0 | 100% | XM_011520152_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X9, mRNA | 6613 | 10507 | 16% | 0.0 | 100% | XM_005252956_3 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X8, mRNA | 6613 | 9783 | 15% | 0.0 | 100% | XM_005252955_3 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X7, mRNA | 6613 | 9091 | 14% | 0.0 | 100% | XM_011520151_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X6, mRNA | 6613 | 9637 | 15% | 0.0 | 100% | XM_011520150_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X5, mRNA | 6613 | 11324 | 17% | 0.0 | 100% | XM_011520149_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X4, mRNA | 6613 | 9814 | 15% | 0.0 | 100% | XM_005252954_3 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X3, mRNA | 6613 | 9172 | 14% | 0.0 | 100% | XM_011520148_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X2, mRNA | 6613 | 9502 | 15% | 0.0 | 100% | XM_011520147_1 |
| PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X1, mRNA | 6613 | 9576 | 15% | 0.0 | 100% | XM_011520146_1 |
| PREDICTED: Homo sapiens elongator acetyltransferase complex subunit 4 (ELP4), transcript | 1775 | 1775 | 2% | 0.0 | 100% | XM_005252865_2 |
| Homo sapiens paired box 6 (PAX6), transcript variant 9, mRNA | 647 | 2630 | 4% | 0.0 | 100% | NM_001310159_1 |

OK, I started by computing an alignment that was a mapping of all **24** transcripts onto the **PAX6** genomic regions as represented in the file **pax6_genomic.fasta**. I used a program called **gmap**, which like **spline** (used in the exercise) is designed to align cDNA/mRNA sequences with corresponding genomic sequences. The version of **gmap** I used runs under **linux** from the command line. It has the advantage over **spline** that it will align more than one cDNA/mRNA sequence against the genome in one run. Unfortunately, it does not generate an output format that can be easily displayed in the way I required here. I did try to persuade a couple of general multiple alignment programs (**clustalw** & **muscle**) to make me a usable alignment, but ran into the same difficulties we experienced in the exercise. I failed to find gap penalties that would get the programs to gap the larger introns. Even if I had succeeded to get the gaps in the right place, I would not have believed them to be placed with sufficient accuracy for the same reasons this was not possible when we tried the same trick with general alignment software for just one cDNA sequence against the genome in the exercise.

So, I made a rough alignment with **clustalw** and edited it to exactly what was suggested by **gmap** using **jalview**. This took **HOURS**. There has to be a better way!! You have already used all the software mentioned except **gmap** and **clustalw**. You will use **clustalw** and see how **jalview** can be used to edit, as well as just view, alignments a little later.

All that effort to show that the region around the forward primer looks like this:

Sequence logo showing the conservation of the pax6 genomic sequence across various primates. The x-axis shows positions 12000 to 12060. The y-axis lists primate accessions. The logo uses four colors: orange, green, red, and blue, representing different nucleotide frequencies at each position.

| | 12000 | 12010 | 12020 | 12030 | 12040 | 12050 | 12060 |
|-----------------------|-----------------|-----------------|------------------|---------------------|-------|-------|-------|
| pax6-genomic/1-34170 | ACAGAGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| FORPRIM/1-25 | | | | | | | |
| REVPRIM/1-26 | | | | | | | |
| NM_001258462.1/1-6922 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001127612.1/1-6880 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001258463.1/1-6860 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001258464.1/1-6868 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001604.5/1-6910 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_000280.4/1-6966 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001258465.1/1-6854 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001310158.1/1-6963 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001310159.1/1-1393 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_011520149.1/1-6093 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_005252955.3/1-5257 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_005252954.3/1-5275 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_005252956.3/1-5652 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_011520150.1/1-5184 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_006718246.2/1-5032 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| XM_011520152.1/1-5074 | -AGCCCCATATT | CGAGCCCCGTGGAAT | CCCAGGGCCCCCAGCC | AGAGGCCAGCATGCAGAAC | A | | |
| NM_001310160.1/1-8177 | | | | | | | |
| NM_001310161.1/1-6729 | | | | | | | |
| XM_005252958.3/1-5411 | | | | | | | |
| XM_011520153.1/1-5080 | | | | | | | |
| XM_011520151.1/1-4912 | | | | | | | |
| XM_011520148.1/1-4954 | | | | | | | |
| XM_011520146.1/1-5155 | | | | | | | |
| XM_011520147.1/1-5112 | | | | | | | |

Showing clearly that the **8** transcripts:

NM_001310160.1
NM_001310161.1
XM_005252958.3
XM_011520153.1
XM_011520151.1
XM_011520148.1
XM_011520146.1
XM_011520147.1

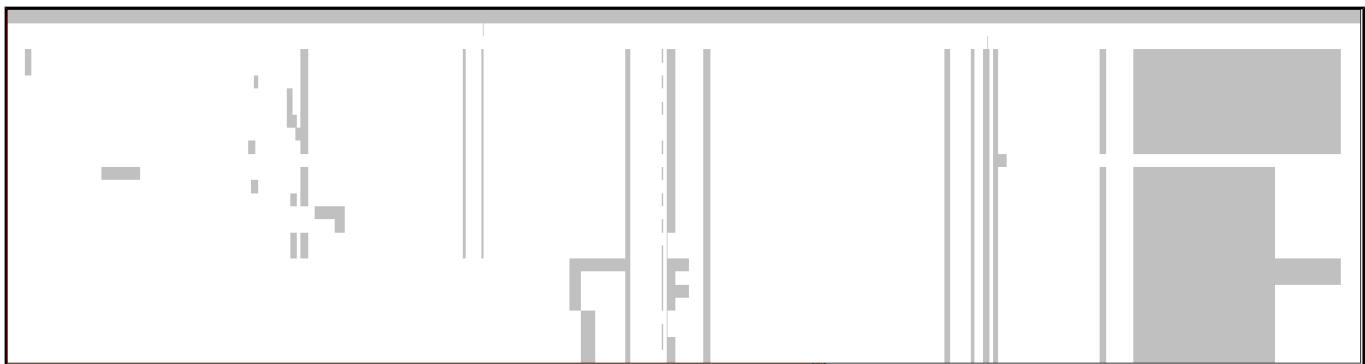
Have the exon that includes the forward primer spliced out and so will not produce any PCR product. Feel free to check this by comparing the textual results of your **blast** of the genomic sequence against the **RefSeq** mRNAs and the results of **PRIMER-BLAST**. I did, it was lots and lots of fun and I ended up content that all was logically consistent.

The alignment around the reverse primer looks like this:

| | 24740 | 24750 | 24760 | 24770 | 24780 | 24790 | 24800 |
|-----------------------|-----------------------------------|----------------------|------------|---------|-------|-----------|---------|
| pax6-genomic/1-34170 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| FORPRIM/1-25 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| REVPRIM/1-26 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001258462.1/1-6922 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001127612.1/1-6880 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001258463.1/1-6860 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001258464.1/1-6868 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001604.5/1-6910 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_000280.4/1-6966 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001258465.1/1-6854 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001310158.1/1-6963 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001310159.1/1-1393 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520149.1/1-6093 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_005252955.3/1-5257 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_005252954.3/1-5275 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_005252956.3/1-5652 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520150.1/1-5184 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_006718246.2/1-5032 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520152.1/1-5074 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001310160.1/1-8177 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| NM_001310161.1/1-6729 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_005252958.3/1-5411 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520153.1/1-5080 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520151.1/1-4912 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520148.1/1-4954 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520146.1/1-5155 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |
| XM_011520147.1/1-5112 | ACACCTAGTCATATTCCATTCAGCAGTAGTTCA | GCACCAAGTGTCTACCAACC | AATTCCACAA | CCCACCA | ACCA | ATTCCACAA | CCCACCA |

All **24** putative transcripts match the reverse primer perfectly. So blast should indeed find **16** of the **24** transcripts sequences in **RefSeq**, and it does.

Jalview offers an overview of the entire alignment. The top row shows the genomic sequence. The second row shows the position of the forward primer. The third row shows the position of the reverse primer.



Except for the order of the transcripts, this view is very similar to the overview graphic generated by **blast**. The transcripts missing the forward primer, which isoform each transcripts represents and the fact that all transcripts match the reverse primer should be very clear.

Finished Dave? Well no, not quite. I wondered why I had included the genomic sequence in my alignment. Finding no answer to that question, I tried to make an alignment of just the primer sequences and the mRNAs. I thought this would be easy. I was wrong. The general programs are still going to get the gaps wrong whatever penalties are used. Some transcripts have exons entirely missing in all other transcripts leaving no clues as to which way round they should be aligned. The scaffold provided by the genomic sequence was essential. So, I made a mRNA only alignment by editing the alignment discussed above with **jalview**. This was easy (although you would not think so given the time it took me to work out how to do it!). I loaded the alignment into **jalview**, deleted the genomic sequence and then removed all empty columns (that is, all columns with no bases in them due to the removal of the genomic sequence). Clever eh? Just because it is there, here are the pictures.

Forward primer region (the primer is right at the end of an exon):

| | 2760 | 2770 | 2780 | 2790 | 2800 | 2810 | 2820 | |
|-----------------------|---|--------------------------------------|------|---------------------------|------|------|------|--|
| FORPRIM/1-25 | - | - | - | CCAGCCAGAGCCAGCATGCAGAAC | - | - | - | |
| REVPRIM/1-26 | - | - | - | - | - | - | - | |
| NM_001258462.1/1-6922 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001127612.1/1-6880 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001258463.1/1-6860 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001258464.1/1-6868 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001604.5/1-6910 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_000280.4/1-6966 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001258465.1/1-6854 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001310158.1/1-6963 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001310159.1/1-1393 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_011520149.1/1-6093 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_005252955.3/1-5257 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_005252954.3/1-5275 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_005252956.3/1-5652 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_011520150.1/1-5184 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_006718246.2/1-5032 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| XM_011520152.1/1-5074 | CCGTGGAAT | CCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAAC | - | - | - | - | - | |
| NM_001310160.1/1-8177 | - | - | - | CTTTCAATTAGCCTTCCATGCATGA | - | - | - | |
| NM_001310161.1/1-6729 | - | - | - | CTTTCAATTAGCCTTCCATGCATGA | - | - | - | |
| XM_005252958.3/1-5411 | - | - | - | CTTTCAATTAGCCTTCCATGCATGA | - | - | - | |
| XM_011520153.1/1-5080 | - | - | - | CTTTCAATTAGCCTTCCATGCATGA | - | - | - | |
| XM_011520151.1/1-4912 | - | - | - | - | - | - | - | |
| XM_011520148.1/1-4954 | - | - | - | - | - | - | - | |
| XM_011520146.1/1-5155 | - | - | - | - | - | - | - | |
| XM_011520147.1/1-5112 | - | - | - | - | - | - | - | |
| Consensus | | | | | | | | |
| | CCGTGGAATCCCGCGGGCCCCCAGCCAGAGCCAGGCATGCAGAACACTTTCAATTAGCCTTCCATGCATGA | | | | | | | |

Reverse primer region:

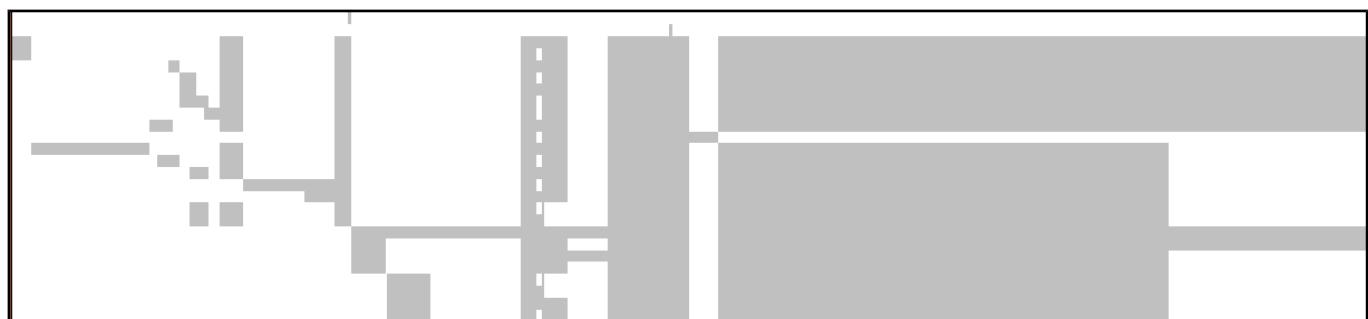
| | 5420 | 5430 | 5440 | 5450 | 5460 | 5470 | 5480 |
|-----------------------|------|--------|-------------------|----------------|----------|------|------|
| FORPRIM/1-25 | - | - | - | - | - | - | - |
| REVPRIM/1-26 | - | - | - | - | - | - | - |
| NM_001258462.1/1-6922 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001127612.1/1-6880 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001258463.1/1-6860 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001258464.1/1-6868 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001604.5/1-6910 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_000280.4/1-6966 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001258465.1/1-6854 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001310158.1/1-6963 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001310159.1/1-1393 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520149.1/1-6093 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_005252955.3/1-5257 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_005252954.3/1-5275 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_005252956.3/1-5652 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520150.1/1-5184 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_006718246.2/1-5032 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520152.1/1-5074 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001310160.1/1-8177 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| NM_001310161.1/1-6729 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_005252958.3/1-5411 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520153.1/1-5080 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520151.1/1-4912 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520148.1/1-4954 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520146.1/1-5155 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |
| XM_011520147.1/1-5112 | AGT | CATATT | CCTATCAGCAGTAGTTT | CAGCACCAAGTGTC | TACCAACC | - | - |

Consensus

AGTCATATTCCCTATCAGCAGTAGTTT CAGCACCAAGTGTC TACCAACC

Overview:

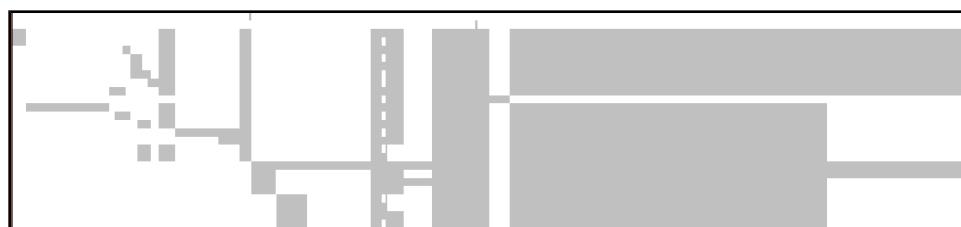
Without the evidence of the genomic sequence, the two leftmost exons could logically swap position. There is no transcript that includes both these exons and no overlap between either and any other exon in any transcript (most clearly verified from the previous **Overview** plot). Thus, there is no exon evidence of the order in which the two should appear.



Now I am done! This has to be the most over the top answer yet, but at least it kept me out of trouble for a while.

How would you tell quickly which isoform was represented by each mRNA listed here?

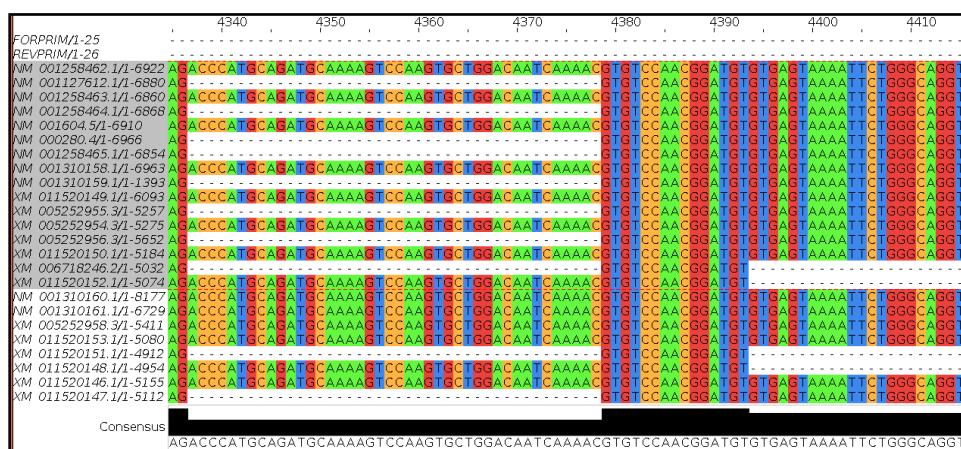
From the illustrations of the last answer (in particular, the **jalview** overviews), it is clear that all the mRNAs that produce a product include the region that determines which isoform is represented. That is, all are one isoform or the other.



| Products on potentially unintended templates | | | |
|---|------------------------------|------|--|
| >NM_001310159_1 Homo sapiens paired box 6 (PAX6), transcript variant 9, mRNA | | | |
| product length = 908 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 114 | | 138 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1021 | | 996 | |
| >NM_001310158_1 Homo sapiens paired box 6 (PAX6), transcript variant 8, mRNA | | | |
| product length = 950 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 496 | | 520 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1445 | | 1420 | |
| >XM_006718246_2 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X11, mRNA | | | |
| product length = 787 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 457 | | 481 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1163 | | 1138 | |
| >XM_011520152_1 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X10, mRNA | | | |
| product length = 749 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 457 | | 481 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1205 | | 1180 | |
| >XM_005252956_3 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X9, mRNA | | | |
| product length = 908 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 876 | | 900 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1783 | | 1758 | |
| >XM_005252955_3 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X8, mRNA | | | |
| product length = 908 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 481 | | 505 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1388 | | 1363 | |
| >XM_011520150_1 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X6, mRNA | | | |
| product length = 950 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 366 | | 390 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1315 | | 1290 | |
| >XM_011520149_1 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X5, mRNA | | | |
| product length = 950 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 1275 | | 1299 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 2224 | | 2199 | |
| >XM_005252954_3 PREDICTED: Homo sapiens paired box 6 (PAX6), transcript variant X4, mRNA | | | |
| product length = 950 | | | |
| Forward primer 1 | CCAGCCAGGCCAGCATGCAGAACAA | 25 | |
| Template 457 | | 481 | |
| Reverse primer 1 | GGTTGGTAGACACTGGTGTGCTGAAACT | 26 | |
| Template 1406 | | 1381 | |

The last two of the mRNAs that produce a product, have a bit chewed out just after the isoform defining region (an exon spliced out, if you prefer). It is logical to suppose these would be the mRNAs from which the two shorter products were generated.

Indeed, looking at the relevant part of the mRNA only alignment shows them to be **XM_006718246** (product length **707**, excluding the **isoform 5a** exon that suggest it codes for a **canonical** protein) and **XM_011520152** (product length **749**, including the extra **42** base pairs suggesting it codes for an **isoform 5a** protein).



All other transcripts that generate PCR products generate products of length either **908** or **950**. Given the difference (**42** base pairs) is exactly the size of the **isoform 5a** exon, it is reasonable to assume the transcripts generating PCR products of length **908** represent **canonical** proteins, whereas the transcripts generating PCR products of length **950** represent **isoform 5a** proteins.

Is the number of “potentially unintended products” as you would you expect, given the evidence from **GeneCards**, **Ensembl** and **blast**?

Yes, I think so, given you accept my investigation (see above) as to why there were only **16** “potentially unintended products” when you might have expected **24**, given your **blast** results. Once **GeneCards** catches up with **RefSeq**, it too will encourage an initial expectation of **24** “potentially unintended products”. **Ensembl** only uses the higher quality **RefSeq** mRNAs. Currently, **Ensembl** implies there to be **7** good quality **RefSeq** mRNAs. I have faith that **Ensembl** will use all **11** when it is updated next.

For all the “potentially unintended products”, the selected primers match exactly. Can you explain this?

Well, of course they do??? All the transcripts found are generated from the same region of genomic DNA and therefore will be identical in all shared regions, including the primer regions. I suppose, in other instances, it would be possible to have transcripts with variation in the regions matching the primers insufficient to stop the primers working? But not in this case.

One might conclude there are no genuinely “unintended” products? All are real **PAX6** transcripts of varying certainty. A genuine unintended product would come from an entirely different part of the genome and would not necessarily match exactly with respect to the primers. They would just need to be “good enough to work”.

The “potentially unintended products” are of different sizes. Can you explain the difference between the possible product lengths?

Are the numbers of “potentially unintended products” of each possible length consistent with your **blast** results?

Yes yes yes! I think both these questions made a bit more sense a few generations of these notes ago. We have already answered them sufficiently I suggest. I refer you to [the answers above](#).

From your investigations of Protein Secondary Structure Prediction with GOR I

How credible would you say was the prediction at amino acid 33?

The original **GOR** predicts a Helix of length 1 at position 33! This is just daft! A single amino acid cannot form a helix all by itself, it must have a few friends to make a believable Helix ... or Beta Sheet, come to that.

Later versions of **GOR** made such silly predictions impossible, preferring to take the second best possibility for all insane predictions. In this case, positions 26, 27 & 33 would all probably be predicted as Beta Sheet (E – for Extended). Wrong (according to **UniprotKB**) but more logical.

Position 33 is, as you have discovered, the amino acid that, when mutated from an Alanine to a Proline, is the major cause of **Aniridia**. As you will confirm later, it is at the end of a Helix critical to the DNA binding properties of the protein. Alanines are fine in Helices. Prolines are not.

How would you rate the prediction overall?

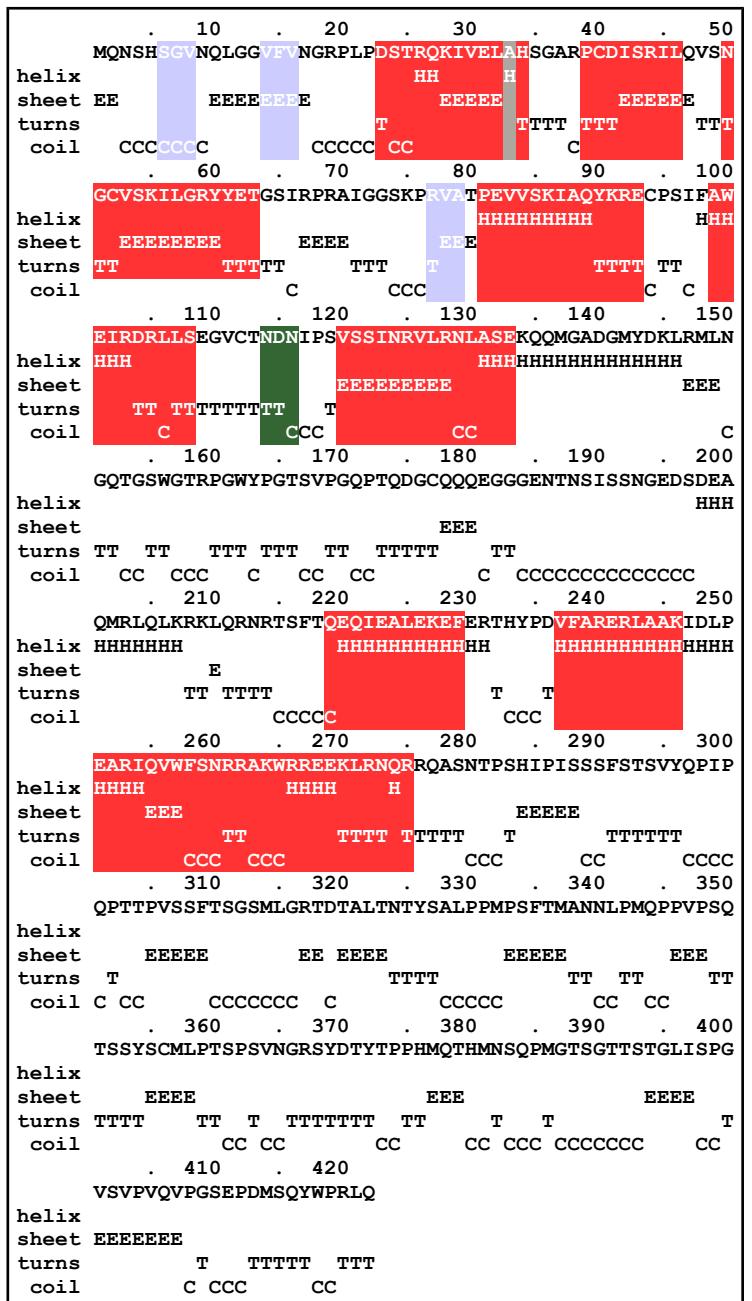
| | | |
|-------------|-----------|----|
| Beta strand | 6 - 8 | 3 |
| Beta strand | 14 - 16 | 3 |
| Helix | 23 - 34 | 12 |
| Helix | 39 - 46 | 8 |
| Helix | 50 - 63 | 14 |
| Beta strand | 77 - 79 | 3 |
| Helix | 81 - 93 | 13 |
| Helix | 99 - 108 | 10 |
| Turn | 114 - 116 | 3 |
| Helix | 120 - 133 | 14 |
| Helix | 219 - 229 | 11 |
| Helix | 237 - 246 | 10 |
| Helix | 251 - 275 | 25 |

Referring to the structure according to **UniProtKB**, I colour the Helices Red and the Beta Sheets Blue. Position 33 I colour Grey. I do not believe the turn predictions, there are far too many! However, as the one predicted does, almost, match the **UniProtKB** assertion, I will highlight it with Green.

The Coils are boring, so I do not colour them at all!

Well, what do you think? It might reach the 60% or so accuracy claimed by the version of **GOR**, but what does that really mean? There are only four possibilities so 25% “accuracy” can be expected by chance. Add a small insight into the relative abundance of each possibility and you could improve on that before doing anything clever.

My, intuitive only, impression is that the program has found some useful insight into the problem, but I cannot say I am overly impressed. Of course, this is just one example. It is unreasonable to make harsh general judgement based on such light evidence. This is, after all, the crudest implementation of a simple method and I have seen it do much better with more compliant proteins.



From your investigations of Protein Secondary Structure Prediction with GOR IV

How does the prediction at position 33 compare with that of garnier?

Well, at least there is no attempt to suggest a one amino acid helix in this case! **GOR IV**, with justice, does not regard this as possible. Such silly predictions suggested by the arithmetic are rejected and replaced by more sensible alternatives computed by considering the likelihoods computed for other possibilities.

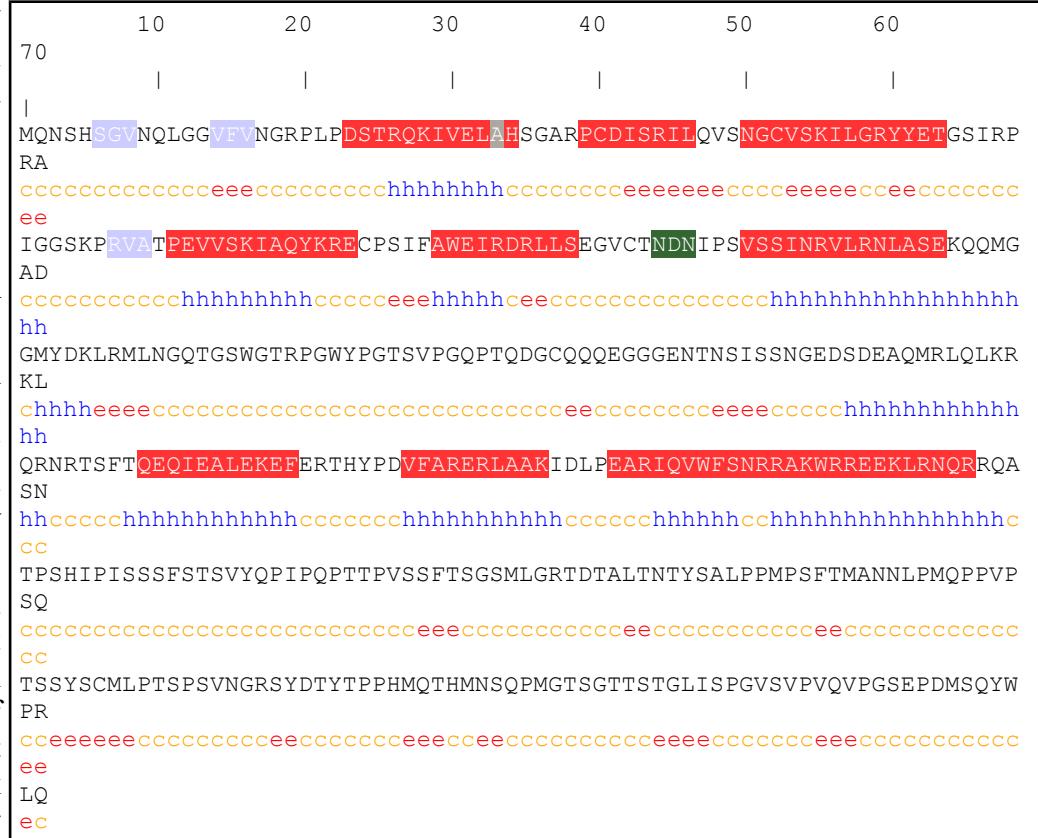
In a nutshell, **GOR IV** predicts position 33 to be at the end of a helix whose existence is supported reasonably well by **UniProtKB**. This is good! **GOR I** predicts position 33 to be a helix of length 1 amino acid in a region weakly suggested to have some sort of structure. This is weak, to say the least.

How would you rate the prediction overall?

I have coloured up the **GOR IV** results in the same way as I did for the **GOR I** results discussed above. Colouring the turn was unnecessary as **GOR IV** does not even try to predict turns.

This prediction is clearly loads better than the original **GOR** managed. In particular:

- The region after the last helix (position **280** or so onwards) is, give or take a few spurious attempts at Beta Sheets, predicted accurately as unstructured (i.e. Coil).
- The predictions for the Beta sheets are slightly worse than **GOR I** managed. Both programs got the second of the three and missed the first entirely, but **GOR I** did pick two of the three positions for the third Beta sheet, **GOR IV** missed it altogether!



- Neither program got the helices quite right, but **GOR IV** was much closer to the right answer (according to **UniProtKB**). The two helices **GOR IV** missed altogether were predicted as largely structured (i.e. Beta Sheet instead of Helix). Generally, **GOR** is pretty reliable at picking structure, but not always the right structure. Knowing this, you could claim that predicting the helices as Beta Sheets beats predicting them as Coil.

I conclude, this is a usefully accurate prediction (as long as you do not take it **TOO** seriously) and certainly a big improvement on **GOR I**.

From your investigations of Protein Secondary Structure Prediction with Jpred

What protein database has **Jpred** chosen to search for protein sequences for the alignment upon which its predictions will be based?

The database **Jpred** instructed **PSI-blast** to use to seek proteins homologous to the **PAX6** query can be determined by looking at the sequence identifiers displayed down the left hand side of the alignment in **Jalview**. The identifiers are constructed from the name of the database and the entry identifier separated by an underline character. So the database is the **UniRef90** cluster database built from the **UniProtKB** database.

The **UniRef** cluster databases comprise entries that are not individual protein sequences, but cluster of similar sequences. In the case of the **UniRef90** database, each entry includes all sequences 90% identical to a given seed sequence. A representative sequence is elected as the only one of the cluster to be considered by such as **PSI-blast**, but clearly, a hit with any representative sequence implies significant similarity with all the sequences of its cluster.

I offer a supplementary exercise to investigate these cluster databases for those to whom they might be of particular interest.

Why do you suppose this database was used in preference to, say UniprotKB?

The reason **Jpred** runs **PSI-blast** is to identify sequences representing as wide a family of proteins as possible, to which a **Query** sequence belongs. For the purpose of structure prediction, there is little value in this collection including many sequences that are essentially identical. A wide variety of sequences, as long as they still are likely to be homologous, is of far greater value than a huge number of sequences. Using a **UniRef** database allows that only the **Representative** sequence of each cluster of very similar sequences will be recognised and aligned by **PSI-blast**. This allows the **PSI-blast MSA** to include an extensive range of variation without being bloated by sequences too similar to be individually interesting.

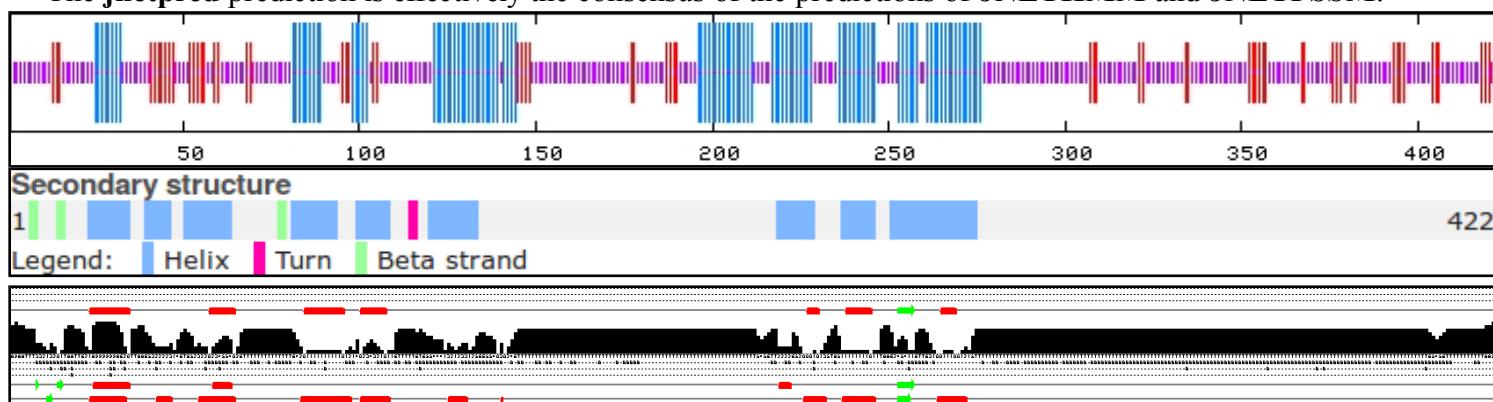
How would you rate the Jpred prediction overall?

Well, frankly, not as wonderful as I was expecting. Better than **GOR IV** (investigated in a supplementary exercise), but still leaves room for improvement? **jnetpred** (essentially the answer) is reasonable. It misses a couple of helices including one that **GOR IV** also overlooks. However, it has considerably less false positive prediction tendencies. The **JNETHMM** predictions are particularly poor, saved by the much more accurate deliberations of **JNETPSSM**.

JNETHMM is a prediction computed from the **Hidden Markov Model (HMM)** representation of the final **PSI-blast MSA**.

JNETPSSM is a prediction computed from the **Position Specific Scoring Matrix (PSSM)** representation of the final **PSI-blast MSA**. **PSI-blast** uses **PSSMs** of the **MSA** of each iteration of its search as a **Query** for the next iteration.

The **jnetpred** prediction is effectively the consensus of the predictions of **JNETHMM** and **JNETPSSM**.



So, can the prediction be improved? **Jpred** is better than this result suggests!

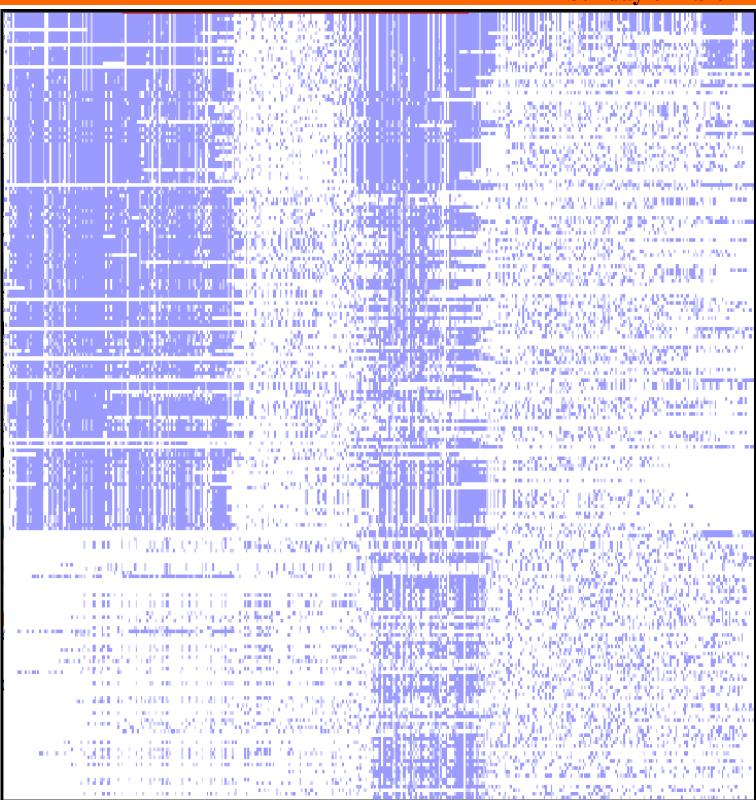
On reflection, maybe just throwing in the entire sequence of **PAX6_HUMAN** and hoping for the best was a little crude? Our protein has two major domains whose secondary structure one might expect to be conserved. **PSI-blast** will gather together a mountain of sequences that have one, or the other, or both of the domains and try to align them as if they were homologous over their entire length (a **global alignment**). **BUT**, they are not all

globally homologous! This means that the alignment of both the domains regions will be polluted by sequence that represent proteins that do not include that domain. This must substantially reduce the quality of the prediction?

This phenomena can be illustrated by choosing to view the **Jalview Overview Window** (available from the **View** pull down menu).

The wider column of blueness at the start of the alignment represents the **paired box** domains. The picture suggests about one third of the aligned sequences do not have a **paired box** domain, but those sequences will have unrelated sequence in that region that will reduce the degree to which the alignment represents the properties of a **paired box** and so also the likelihood of a sensible structure prediction.

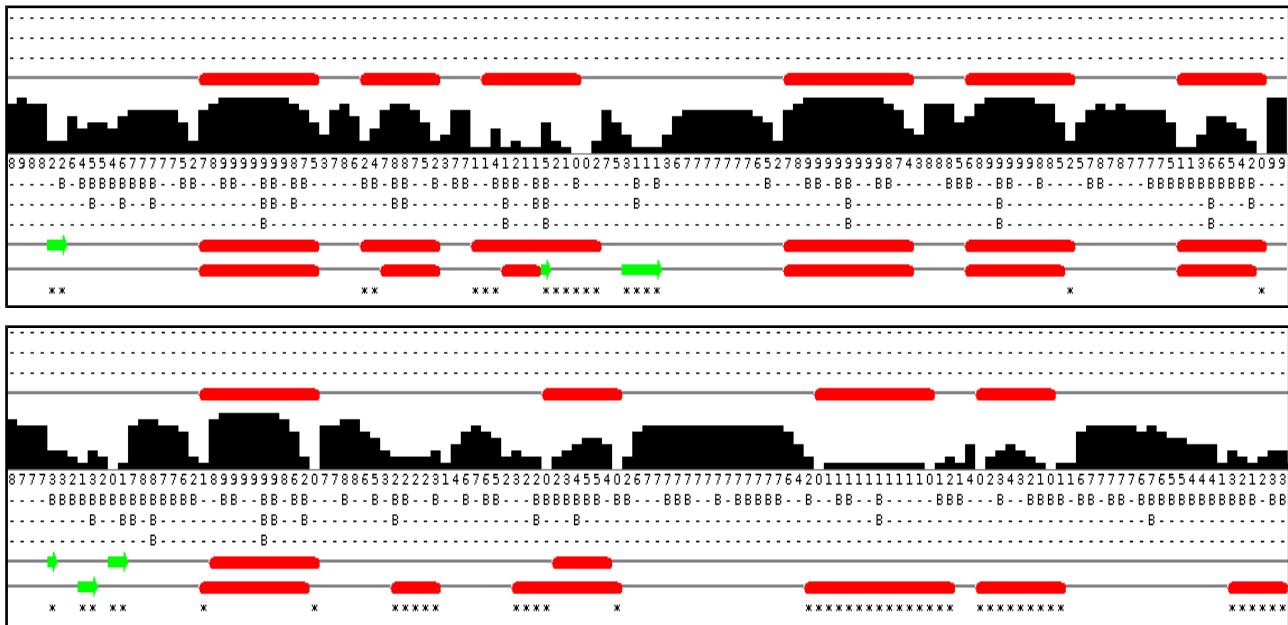
The problem for the more common **homeobox** domain looks less severe, however, the alignment clearly includes many sequences that do not look to have a **homeobox** domain.



So, what to do? I suggest the two domains might be investigated separately? Why not run **Jpred** twice, once with just the **PAX6 HUMAN** paired box region and then again with just the **homebox** region.

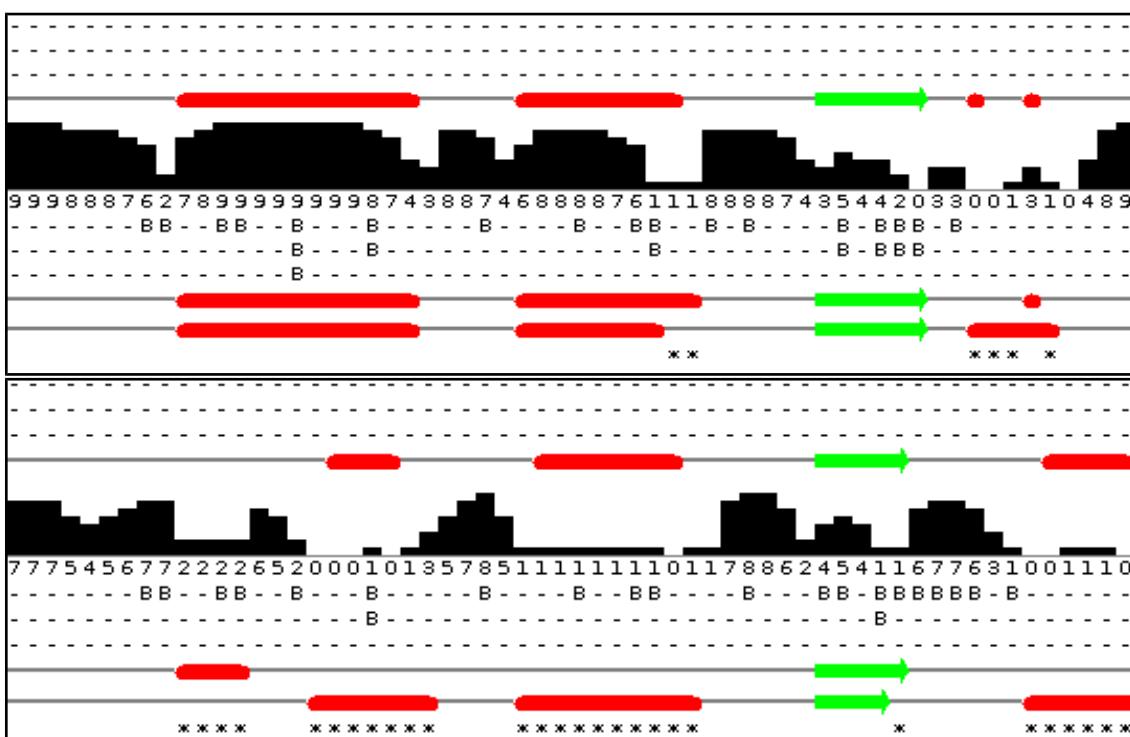
I have done this for you and will now show you the results, however, should you wish to try it yourself, you already have the isolated sequence of both domains saved in local files. The sequence of the **paired box** region should be in a file called **pax_domain.fasta**. The **homeobox** sequence should be in a file called **homeobox_domain.fasta**. Just run **Jpred** again with each sequence and you should get results very similar to mine.

First the new **paired box** prediction (top) compared to the original (bottom).



Massively improved I would suggest. All helices present and accurately placed. The **JPREDHMM** prediction, in particular, is very much improved. The Beta Sheet predictions seem weak? It finds only one (accurately) of the three that **UniProtKB** suggests to be present. I wonder why, but the helices for the paired box domain specific prediction are excellent.

And so to the **homeobox** specific results. Once more, the new **homeobox** prediction (top) compared to the original (bottom).



Searching PROSITE

What is the signature pattern for N-myristoylation site?

From the database entry, it can be seen that the pattern is 6 positions wide. 2 of those positions can be any amino acid. Only one position is fully specified. Not too demanding on the whole. I would expect this to match most proteins of any size and not always because there was an **N-myristoylation** site.

MYRISTYL, PS00008; N-myristoylation site (PATTERN with a high probability of occurrence!)

- Consensus pattern:
G-[EDRKHPFYW]-x(2)-[STAGCN]-[P][GistheN-myristoylationsite]

How would you interpret this pattern?

The pattern is explained in the database thus.

- The N-terminal residue must be glycine.
- In position 2, uncharged residues are allowed. Charged residues, proline and large hydrophobic residues are not allowed.
- In positions 3 and 4, most, if not all, residues are allowed.
- In position 5, small uncharged residues are allowed (Ala, Ser, Thr, Cys, Asn and Gly). Serine is favored.
- In position 6, proline is not allowed.

The description is not entirely an honest reflection of the information to which the scanning software will respond. The software is given to understand that **ANY** amino acid can occur in positions **3** and **4**. The software has no way to know that “**Serine** is favoured” in position **5**! Maybe you think that my pointing out these transparent truths makes me an intolerable pedant? Well ... so is the computer!

How many N-myristoylation sites did ScanProsite suggest there might be in PAX6_HUMAN?

| PS00008 MYRISTYL N-myristoylation site : | |
|--|--------|
| 13 - 18: | GVfvNG |
| 36 - 41: | GArpCD |
| 110 - 115: | GVctND |
| 151 - 156: | GQtgSW |
| 154 - 159: | GSwgTR |
| 157 - 162: | GTrpGW |
| 182 - 187: | GGgeNT |
| 183 - 188: | GGenTN |
| 312 - 317: | GSmlGR |
| 387 - 392: | GTsgTT |
| 390 - 395: | GTtsTG |

11, is the short answer. A site every **40** amino acids or so.

How many real N-myristoylation sites would you guess there might be in PAX6_HUMAN?

It is not really possible to answer this question from the evidence of this exercise. Intuitively, I would expect a large number of false positives from as weakly specified motif as this one. It has been suggested of this **PROSITE** pattern, by researchers looking at more sophisticated detection methods, that:

“**PS00008** of **PROSITE** constructed from a small dataset ... produces a great number of not only false positive but false negative predictions.”

Good enough for me not to believe the majority of these predictions to be reliable. Not good enough for me to hazard a meaningful guess as to how many real sites I would expect in this particular protein.

Searching Pfam

Would you have found anything of interest had you chosen “to search for Pfam-B matches”?

I did not find it straight forward to persuade the search to include **Pfam-B** entries.

In the end, I set up the search as required just to search **Pfam-A**. Then, click on the truly tiny **here** link at the end of the sentence suggesting “*You can set up your own search parameters ...*”.

QUICK LINKS

- [SEQUENCE SEARCH](#)
- [VIEW A PFAM FAMILY](#)
- [VIEW A CLAN](#)
- [VIEW A SEQUENCE](#)
- [VIEW A STRUCTURE](#)
- [KEYWORD SEARCH](#)

ANALYZE YOUR PROTEIN SEQUENCE FOR PFAM MATCHES

Paste your protein sequence here to find matching Pfam families.

MONSHGUNLGGGVENVGRPLPDSTROKIVELAHSGARPCDLSRLQVSNQCVSKILORY
YEGSIRPRAIGGSKERVATPEVVKSIQAOYKRECPSPFAMEFLRDLLSEGVCTNDNIPSV
SSINRVLBNLASEKQOMGADGMYDKLRMLNGOTGSNCTRGHNPCTSVPGOPTQDGCCQO
EGGENTNSLSSNGEDSDEAUMRLKRNLRNRTSETQEQALEKEFERTHYPDVEAR
ERLAALKTDLPEARIQWESNRRAKWRREEKLRNORBROASNTTSHPPLSSFESTSYXQTP
OPTPVSSFTSGSMLGRQTDTALNTYSLAPPMPSETMANNLPMOPPVPSOTSSYSCLPT
SERVNGSYDTTPPHMUTHNSUPMTSGLISGLTSPGVSVVWUPGSEFDUMGQWQFBR
LQ

This search will use an E-value of 1.0. You can set your own search parameters and perform a range of other searches [here](#).

JUMP TO

A new search form! I pause to feel badly treated in that I have to re-enter my sequence! I click the Search for **PfamBs** box, reflecting as I do so, how nice that button would have looked on the previous search form?

With a triumphant flourish, I click on the **Submit** button.

Sequence search

Find Pfam families within your sequence of interest. Paste your protein sequence into the box below, to have it searched for matching Pfam families. [More...](#)

Sequence: MONSHGUNLGGGVENVGRPLPDSTROKIVELAHSGARPCDLSRLQVSNQCVSKILORY
YEGSIRPRAIGGSKERVATPEVVKSIQAOYKRECPSPFAMEFLRDLLSEGVCTNDNIPSV
SSINRVLBNLASEKQOMGADGMYDKLRMLNGOTGSNCTRGHNPCTSVPGOPTQDGCCQO
EGGENTNSLSSNGEDSDEAUMRLKRNLRNRTSETQEQALEKEFERTHYPDVEAR
ERLAALKTDLPEARIQWESNRRAKWRREEKLRNORBROASNTTSHPPLSSFESTSYXQTP
OPTPVSSFTSGSMLGRQTDTALNTYSLAPPMPSETMANNLPMOPPVPSOTSSYSCLPT
SERVNGSYDTTPPHMUTHNSUPMTSGLISGLTSPGVSVVWUPGSEFDUMGQWQFBR
LQ

Cut-off Gathering threshold Use E-value

E-value: 1.0

Search for PfamBs Note that we search only the 20,000 largest Pfam-B families

Submit **Reset** **Example**

NOTHING!! Well one use to find a **PfamB** hit that made all the fiddling around make a very small amount of sense, but now?? **NOTHING!!!** They claim the hit one got previously was not a worthy hit ... but ... but ... it was a hit!!! AND, I had a very nice story about how it fitted in with all that we have discovered previously. One, in common with dear Victoria, is NOT amused!

2015.08.08: So you thought that was bad Dave Mawr!!! ... Now the little button has gone altogether and cannot search **PfamB** at all???? Query sent to Help.

2015.08.10: In reply to the question “... Searching **PfamB** - Is this no longer possible? ... “

“ ... Correct - we are not longer producing **Pfam-Bs**, largely because most of the clusters not covered by **Pfam** are really meaningful potential new domains. Our recommendation now, is to take the piece of sequence of interest and run it using the **HMMER** webserver.

<http://www.ebi.ac.uk/Tools/hmmer/search/phmmер>

This will then produce a set of results that essentially provide you with the same information as a **Pfam** entry.
... “

This makes sense only if you change **really** to **rarely** in line 2? I assume this is what was meant. I also assume **PfamB** still exists, in spirit at least, ... as a source to discover new **PfamA** entries? But, users must effectively run **HMMER** themselves if they wish to search beyond what is offered by **PfamA** ... now consistently referred to as **Pfam**? Hmm, maybe I try to clear this up a bit sometime?

Searching for Helix-Turn-Helix motifs

To which, if any, of the expected HTH motifs does this prediction correspond?

Using all the defaults, there is just one prediction:

Sequence: FARERLAAKIDLPEARIQVWFS
 | |
 238 259

Looking again at the reported secondary structure in UniProtKB, I would expect there to be 3 HTH motifs roughly at:

39 → 63
 99 → 116
 237 → 275

So here we are looking at the second expected HTH. That is, the one associated with the helical triplet of the HomeoBox domain.

| | | | |
|---------------|-----|-----|----|
| <u>STRAND</u> | 6 | 8 | 3 |
| <u>STRAND</u> | 14 | 16 | 3 |
| <u>HELIX</u> | 23 | 34 | 12 |
| <u>HELIX</u> | 39 | 46 | 8 |
| <u>HELIX</u> | 50 | 63 | 14 |
| <u>STRAND</u> | 77 | 79 | 3 |
| <u>HELIX</u> | 81 | 93 | 13 |
| <u>HELIX</u> | 99 | 108 | 10 |
| <u>TURN</u> | 114 | 116 | 3 |
| <u>HELIX</u> | 120 | 133 | 14 |
| <u>HELIX</u> | 219 | 229 | 11 |
| <u>HELIX</u> | 237 | 246 | 10 |
| <u>HELIX</u> | 251 | 275 | 25 |

To which, if any, of the expected HTH motifs does the new prediction correspond?

The new prediction is

Sequence: PCDISRILQVSNGCVSKILG
 | |
 39 58

Near enough to the HTH expected for the first helical triplet of the PairedBox domain for me.

Can you suggest anything particular about the third putative HTH motif that might explain its reluctance to be discovered?

Nope which is why one should answer the questions straight away! I must have had a theory at one time?

It is possible to find this third HTH by using the old scoring matrix and an SD limit of 0.8

However, by loosening things up this far, one gets seven answers instead of three. Fours out of the seven are wrong (well, one supposes so at least).

From your investigations of Domain & Motif identification using Interpro

Do you think it a good idea for **Interpro** to offer feature prediction programs as well as domain database searches?

Well ... why not? The purpose of **InterProScan** is to associate regions of query proteins with **Interpro** domains. This was originally achieved was, exclusively, by simply comparing a query sequence with all entries of relevant individual domain databases. These entries being representations of alignments of examples of specific domains constructed by homology searching (i.e. **blast** and similar).

I would suggest including a few predictor programs would provide extra evidence gathered from more general, more theoretical definitions of domains. I would imagine the inclusion of these program has improved and widened the picture provided by **InterProScan**.

Searching domain databases, typically composed of **HMM profiles**, such as **Pfam**, **Prosite** and **PRINTS** is quite different to running the predictor programs. As I cannot improve on the justification of this claim offered to me by Geoff Barton (Head of the group responsible for **Jalview**, **Jpred**, **Jnet** and much more), I will just reproduce his explanation here:

“ ... The main difference is that with an **HMM profile** you have a "specific" example of a domain or motif whereas with something like **COILS**, you have something trained across all examples.

For example, for secondary structure prediction, you could (a) do predictions of alpha-helix and beta-strand just by aligning a sequence to a protein of known structure, or an **HMM** from a family of aligned proteins of known structure. This is a specific case of secondary structure in the context of one protein family. Or (b) you can train a predictor from **ALL** protein families and then apply this. The advantage of (a) is it is very specific to the individual protein family and so should be more accurate for that family. The disadvantage is that it does not generalise to proteins that are not very like the specific example. The advantage of (b) is that it will work with any protein but will likely be less accurate than (a) for proteins that fit into the (a) category. ... “

Do you think the Coil prediction might be correct?

I do not recall anything in what we have discovered thus far that would directly suggest there should be a **coiled coil** here, in the middle of the **HTH**. However, wikipedia does suggest **coiled coils** are associated with **transcription factors** (which **pax6_human** is).

“ ... Many **coiled coil**-type proteins are involved in important biological functions such as the regulation of **gene expression**, e.g. **transcription factors**. ... ”

I think I would not be overly convinced by this prediction, but I would not make that judgement with any great confidence. The all knowing **wikipedia** says:

“ ... **Coiled coils** usually contain a repeated pattern, **hxxhcxc**, of hydrophobic (**h**) and charged (**c**) amino-acid residues, referred to as a **heptad repeat**. ... ”

Geoff Barton comments:

“ ... Sometimes the pattern that is particular to **coiled-coils** also turns up in other helices that pack against each other. You would need to look at some examples of coiled-coil structures to see if the example you are using fits structurally. ... ”

Which seems very reasonable. The **heptad repeat** pattern could easily occur just by chance. **COILS** surely cannot predict the structure of the helices well enough to make an assured judgement? **COILS** offers a suggestion the user must follow up with other resources.

There is also the evidence that **Jpred**, possibly using the **COILS** program disguised as **LUPAS**, did not detect any coiled coils. This could be for a number of reasons. Possibly **LUPAS** is not the same program as **COILS**, or it is a different version, or **Jpred** runs **COILS**, but with different parameters.

Not many clear and confident answers in Bioinformatics are there!

From your investigations of Multiple Sequence Alignment

ClustalX

How might you have saved the need to recompute the alignment by selecting an **Edit** option other than **Remove All Gaps**?

Pretty sure using **Remove Gap-Only columns** rather than **Remove All Gaps** would have got to the second alignment in one step. I struggle to see how this could fail, but cannot convince myself it would be absolutely certain to work. Maybe some of the sequences that were removed would subtly alter the alignment calculations? Doubtful, given how crude the whole thing is. Anyway, it would have been good enough for me in "Real Life" for this data. I did not suggest this approach as we had to make a **Fasta** format file with the entire sequence set to be aligned by the alternative software as a by product of working with **clustalX**. This would not be easily possible if the **Remove Gap-Only columns** short cut was taken.

Muscle

How do the options for the **OUTPUT TREE** relate to the output files of **ClustalX** and the difference between the way that **ClustalX** and **muscle** work?

Comment on how one might choose between the range of options offered for the aligned parameter?

Interpro:

Relationships: PARENT/CHILD; CONTAINS/FOUND IN

The PARENT/CHILD relationship is used to indicate family/subfamily relationships defined by the member database methods in the entries. To be a CHILD, >75% of the protein set of the CHILD must be represented in the PARENT. If an InterPro PARENT has more than one InterPro CHILD a protein sequence should not be found in the match table of more than one of these children. If one InterPro entry is described as the child of another InterPro entry, this implies that the child entry is more specific than the parent, and that in all cases a protein sequence match to the child entry implies a match to the parent. Signatures for the parent and child entries must overlap by >50% of their sequence and there must be no adjacent signatures to the CHILD that are also covered by one or more of the PARENT signatures. A list of the PARENT/CHILD relationships by InterPro entry accession is available from the ftp site: [ParentChildTreeFile.txt](#).

The CONTAINS/FOUND IN relationship is used to indicate features of the entry that are not defined by Parent/Child relationships, these include: Regions, Domains, Repeats and Sites. For a CONTAINS/FOUND IN relationship to be established, 40% or above of the proteins in the InterPro entry must contain the feature. Some features can be found in more than one type of protein or family of proteins, but is not children in the family sense. Features may be structural or functional and can be found in proteins with different domain organisations. The CONTAINS/FOUND IN relationship, is therefore useful in linking InterPro entries which are associated by composition but are not related hierarchically.

Taxonomy coverage:

Taxonomy Coverage

The Taxonomy Coverage aims to provide 'at a glance' view of the taxonomic range of the sequences associated with each InterPro entry and the number of sequences associated with each lineage. The taxonomic lineages are 'clickable' and provide a pop-up, which displays the tax-ID, the taxonomy and taxonomic subgroup(s)/species having matches to proteins, the protein match counts and a FASTA link. Clicking on the taxonomy or taxonomic subgroup(s)/species links to the protein overview matches for the selected taxonomy. Clicking on the FASTA box will download the complete set of FASTA sequences for the selected taxonomy of the entry.

The lineages were carefully selected to provide a view of the major groups of organisms. The circular display has the taxonomy-tree root as its centre. Selected model organisms populate the outer most circle. Nodes of the taxonomy-tree are placed on the inner circles. Radial lines lead to the description for each node. No significance is attached to the position of the node on a particular inner-circle, other than convenience, though some attempt has been made to group nodes. The nodes themselves are either true taxonomy nodes and have a NCBI taxonomy number or are artificial nodes created for this display; of which there are three: **Unclassified**, **Other Eukaryotes** (Non-Metazoa) and the **Plastid Group**.

Artificial Taxon: **Unclassified** contains the following NCBI taxon groups:

- Taxonomy:12884 Viroids
- Taxonomy:12908 unclassified sequences
- Taxonomy:28384 other sequences

The Eukaryota (TAXONOMY:2759) comprises 29 taxons, these have been grouped into two artificial taxons and one existing taxon:

Fungi/Metazoa (TAXONOMY:33154); Node **Metazoa**

Artificial Taxon; **Plastid Group**, this contains the following NCBI taxon groups:

- Taxonomy: 2763 Rhodophyta
- Taxonomy: 2830 Haptophyceae
- Taxonomy: 3027 Cryptophyta
- Taxonomy: 33090 Viridiplantae
- Taxonomy: 33630 Alveolata
- Taxonomy: 33634 stramenopiles
- Taxonomy: 33682 Euglenozoa
- Taxonomy: 38254 Glaucocystophyceae
- Taxonomy: 339960 Katablepharidophyta

Each taxonomic group within this artificial taxon contains organisms that have a plastid.

Artificial Taxon; **Other Eukaryotes** (Non-Metazoa), this comprises the following NCBI taxon groups:

- Taxonomy: 5719 Parabasalidea
- Taxonomy: 5752 Heterolobosea
- Taxonomy: 66288 Oxymonadida
- Taxonomy: 136087 Malawimonadidae
- Taxonomy: 154966 Nucleariidae
- Taxonomy: 193537 Centroheliozoa
- Taxonomy: 207245 Diplomonadida group
- Taxonomy: 543769 Rhizaria
- Taxonomy: 554296 Apusozoa
- Taxonomy: 554915 Amoebozoa
- Taxonomy: 556282 Jakobida

Each taxonomic group within this artificial taxon are the remaining taxonomic groups of the NCBI taxon:2759, which are not in the Plastid Group and are not Fungi/Metazoa (TAXONOMY:33154).

Overlapping Interpro entries

Overlapping InterPro Entries

This section displays entries that share more than 70% of their proteins. Such overlaps define PARENT/CHILD and CONTAINS/FOUND IN relationships between InterPro entries.

IPR009007

Numbers of overlapping proteins

Average numbers of overlapping amino acids

In the above example, InterPro entry IPR011969 contains proteins which are also found in IPR009007 as a result of the protein signatures of the two entries overlapping.

The two entries have been compared firstly by counting the number of proteins which are common to both, the results of which are displayed in the Venn diagram on the left, and secondly by calculating the average overlap of the protein signatures, in amino acids, with the results displayed in the bar diagram on the right.

Venn diagram display of the overlap of proteins common to both entries:

- The purple intersection contains the number of overlapping proteins common to both IPR009007 and IPR011969, which is 31 in this case.
- The pink section on the left is the number of proteins found in IPR009007 but not IPR011969, which is 35378.

Bar diagram display of the average amino acid overlap between the protein signatures:

The average number of amino acids overlapping in the sequences of the 31 proteins common to both entries is then calculated, with the results displayed in the bar diagram on the right. The bar diagram display is only shown for 'Domain - Domain' relationships.

- The purple segment in the middle shows the average number of amino acids overlapping between IPR009007 and IPR011969 for the 31 proteins, in this case 104.
- The pink segment shows the average number of amino acids found in IPR009007, but not IPR011969, for the 31 proteins, which is 0.
- The blue segment shows the average number of amino acids found in IPR011969, but not IPR009007, for the 31 proteins, which is 15.

The results of these comparisons are used to calculate the percentage overlap score, with all scores greater than 70% displayed on the InterPro pages. In this example, since all proteins found in IPR011969 are also found in IPR009007, and all the amino acids from IPR009007 overlap with those from IPR011969, the percentage overlap score is 100%.

Muscle:

- The blue section on the right is the number of proteins found in IPR011969 but not IPR009007, which is 0; i.e. all proteins associated with IPR011969 occur in IPR009007.

How do the options for the **OUTPUT TREE** relate to the output files of **ClustalX** and the difference between the way that **ClustalX** and **muscle** work?_____

none

From first iteration

From second iteration

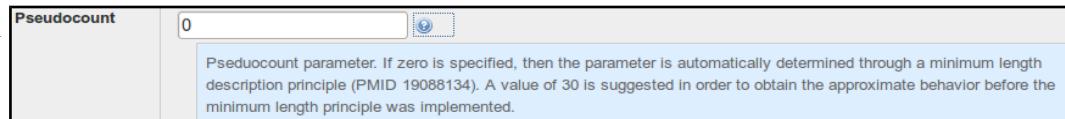
Comment on how one might choose between the range of options offered for the aligned parameter?_____

Clearly?

aligned

What do you suppose the choice of Pseudocount might influence?

I clicked with confidences upon the link to the help. It opined as illustrated.



I suppose the next step is to read PMID 19088134? There is most certainly no elucidation amongst the strange of words offered here?

The article **Abstract** says:

“Position specific score matrices (**PSSMs**) are derived from multiple sequence alignments to aid in the recognition of distant protein sequence relationships. The **PSI-BLAST** protein database search program derives the column scores of its **PSSMs** with the aid of **pseudocounts**, added to the observed amino acid counts in a multiple alignment column. In the absence of theory, the number of **pseudocounts** used has been a completely empirical parameter. This article argues that the minimum description length principle can motivate the choice of this parameter. Specifically, for realistic alignments, the principle supports the practice of using a number of **pseudocounts** essentially independent of alignment size. However, it also implies that more highly conserved columns should use fewer **pseudocounts**, increasing the inter-column contrast of the implied **PSSMs**. A new method for calculating **pseudocounts** that significantly improves **PSI-BLAST**'s; retrieval accuracy is now employed by default.”

The article itself, continues in like vein how about we close our eyes and accept the defaults? I would just wonder why the whole thing does not commence with, at least an attempt, to answer the question in the forefront of my inquiry, which is .. “**WHAT, in the current context, IS a pseudocount?**”. I do not believe it is as tricky as they appear to wish us to believe. I will try again later, when my view of the world is less storm infested.

*****NOTES*****

HelixTurnHelix

helixturnhelix uses the method of Dodd and Egan and finds helix-turn-helix nucleic acid binding motifs in proteins.

The helix-turn-helix motif was originally identified as the DNA-binding domain of phage repressors. One alpha-helix lies in the wide groove of DNA; the other lies at an angle across DNA.

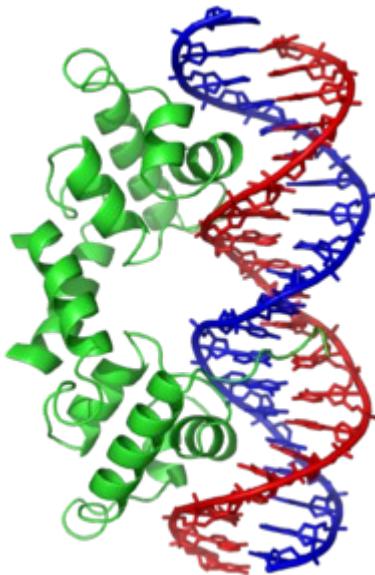
The old (1987) data has a motif length of 20 residues, whilst the default data (Ehth.dat) has a motif length of 22 residues.

With care these can be replaced to suit your data sets. If the files are placed in the following directories they will be used in preference to the files in the EMBOSS distribution data directory:

- . (your current directory)
- .embossdata
- ~/ (your home directory)
- ~/.embossdata

Here is the default file:

| # | R | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | Total | Exp |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|-------|-----|
| # | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| A | 2 | 1 | 3 | 14 | 10 | 12 | 75 | 6 | 15 | 9 | 1 | 1 | 4 | 3 | 8 | 15 | 4 | 4 | 4 | 11 | 0 | 10 | 212 | 995 | |
| C | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 14 | 106 | |
| D | 0 | 1 | 0 | 1 | 14 | 0 | 0 | 14 | 1 | 0 | 5 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 43 | 556 |
| E | 4 | 5 | 0 | 11 | 26 | 0 | 0 | 16 | 9 | 3 | 3 | 0 | 3 | 12 | 13 | 0 | 0 | 2 | 0 | 1 | 13 | 6 | 127 | 669 | |
| F | 4 | 0 | 4 | 0 | 0 | 4 | 0 | 1 | 0 | 10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 22 | 0 | 49 | 358 | |
| G | 9 | 7 | 1 | 4 | 0 | 0 | 8 | 0 | 0 | 0 | 50 | 0 | 6 | 0 | 7 | 1 | 0 | 3 | 1 | 1 | 0 | 4 | 102 | 761 | |
| H | 4 | 3 | 1 | 1 | 2 | 0 | 0 | 3 | 2 | 0 | 5 | 0 | 3 | 3 | 0 | 2 | 0 | 2 | 4 | 5 | 0 | 2 | 42 | 225 | |
| I | 10 | 0 | 13 | 3 | 2 | 15 | 0 | 4 | 9 | 4 | 0 | 17 | 0 | 2 | 0 | 1 | 31 | 1 | 4 | 8 | 16 | 1 | 141 | 583 | |
| K | 4 | 4 | 6 | 11 | 12 | 1 | 1 | 14 | 11 | 0 | 5 | 2 | 2 | 7 | 2 | 1 | 0 | 5 | 8 | 4 | 5 | 15 | 120 | 516 | |
| L | 16 | 1 | 17 | 0 | 1 | 35 | 0 | 3 | 12 | 31 | 0 | 22 | 0 | 2 | 1 | 1 | 22 | 1 | 1 | 12 | 20 | 0 | 198 | 954 | |
| M | 7 | 0 | 2 | 1 | 1 | 1 | 0 | 0 | 5 | 7 | 1 | 10 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 1 | 42 | 275 |
| N | 0 | 8 | 0 | 1 | 0 | 0 | 0 | 2 | 1 | 1 | 14 | 0 | 8 | 1 | 4 | 2 | 0 | 4 | 9 | 0 | 0 | 11 | 66 | 383 | |
| P | 1 | 6 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 13 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 34 | 403 | |
| Q | 2 | 1 | 21 | 9 | 11 | 0 | 0 | 9 | 8 | 0 | 0 | 2 | 1 | 17 | 7 | 12 | 0 | 3 | 12 | 5 | 3 | 9 | 132 | 437 | |
| R | 9 | 10 | 14 | 9 | 5 | 0 | 1 | 16 | 10 | 0 | 1 | 0 | 1 | 17 | 8 | 7 | 0 | 17 | 28 | 3 | 0 | 16 | 172 | 609 | |
| S | 2 | 17 | 0 | 8 | 4 | 1 | 6 | 1 | 2 | 2 | 3 | 0 | 37 | 1 | 25 | 5 | 0 | 29 | 3 | 0 | 1 | 5 | 152 | 552 | |
| T | 6 | 24 | 3 | 12 | 1 | 5 | 0 | 2 | 2 | 4 | 0 | 5 | 20 | 4 | 3 | 39 | 0 | 4 | 1 | 0 | 4 | 3 | 142 | 512 | |
| V | 7 | 3 | 1 | 1 | 2 | 16 | 0 | 0 | 2 | 12 | 0 | 29 | 0 | 5 | 3 | 3 | 32 | 0 | 7 | 8 | 7 | 0 | 138 | 724 | |
| W | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 21 | 0 | 0 | 0 | 27 | 105 | |
| Y | 2 | 0 | 4 | 3 | 0 | 1 | 0 | 0 | 2 | 4 | 0 | 1 | 1 | 2 | 0 | 2 | 0 | 15 | 5 | 7 | 0 | 0 | 49 | 267 | |



The λ repressor of bacteriophage lambda employs a helix-turn-helix (top; green) to bind DNA (bottom; blue and red).

In proteins, the helix-turn-helix (HTH) is a major structural motif capable of binding DNA. It is composed of two α helices joined by a short strand of amino acids and is found in many proteins that regulate gene expression. It should not be confused with the helix-loop-helix domain.

Its discovery was based on similarities between the genes for Cro, CAP, and λ repressor, which share a common 20-25 amino acid sequence that facilitates DNA recognition. In particular, recognition and binding to DNA is done by the two α helices, one occupying the N-terminal end of the motif, the other at the C-terminus. In most cases, such as in the Cro repressor, the second helix contributes most to DNA recognition, and hence it is often called the "recognition helix". It binds to the major groove of DNA through a series of hydrogen bonds and various Van der Waals interactions with exposed bases. The other α helix stabilizes the interaction between protein and DNA, but does not play a particularly strong role in its recognition.

DPJ – 2015.09.14