

Immune repertoire annotation

A RepSeq data analysis tutorial

Mikhail Shugay, PhD

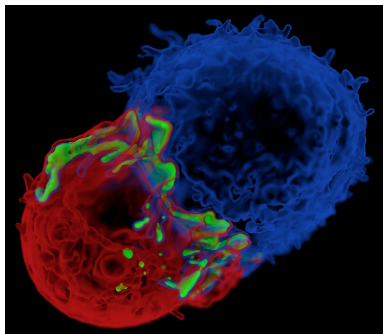
Skoltech, MA03172 course [Term 2, 2017-2018]

December 5, 2017

Outline

T-cell receptor

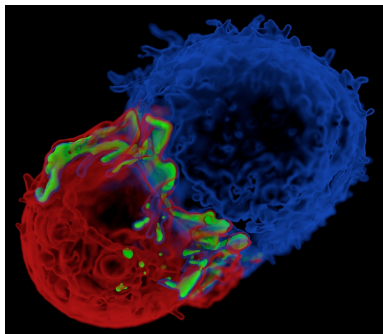
T-cell:APC contact



From James and Vale, Nature
2012,
<https://valelab.ucsf.edu/images/>

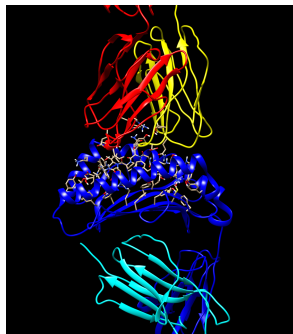
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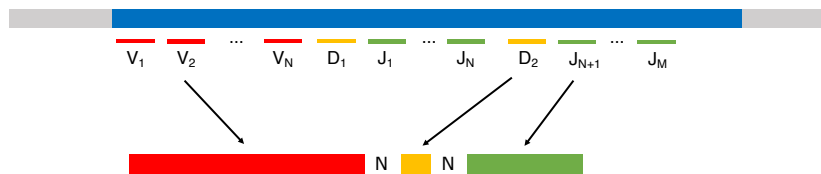
TCR:pMHC structure



PDB:1ao7, rendered using
UCSF chimera, colored by
chain

VDJ rearrangement

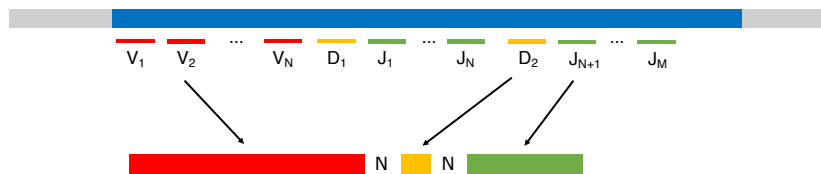
An example schema for TCR β locus



Variable, Diversity and Joining are chosen at random, V-D and D-J junctions are filled with non-template N bases.

VDJ rearrangement

An example schema for TCR β locus



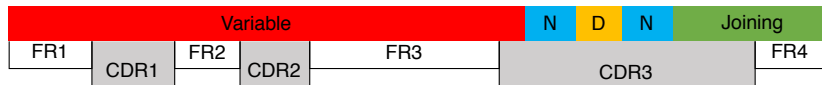
Variable, Diversity and Joining are chosen at random, V-D and D-J junctions are filled with non-template N bases.

VDJ rearrangement mechanism can be efficiently recaptured with a probabilistic model [Murugan et al. PNAS 2012]

$$\begin{aligned} P(\sigma) &= P(V)P(D, J) \\ &\times P(\#del_V|V)P(\#del_J|J)P(\#del_{D5}, \#del_{D3}|D) \\ &\times P(\#ins_{VD})P(\#ins_{DJ}) \prod_{i \in ins_{VD}} P(b_i|b_{i-1}) \prod_{i \in ins_{DJ}} P(b_i|b_{i+1}) \end{aligned}$$

TCR regions

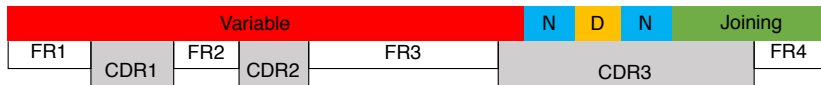
A TCR chains consists of the following regions:



In total there are four framework (FRs) and three complementarity determining regions/loops (CDRs).

TCR regions

A TCR chains consists of the following regions:

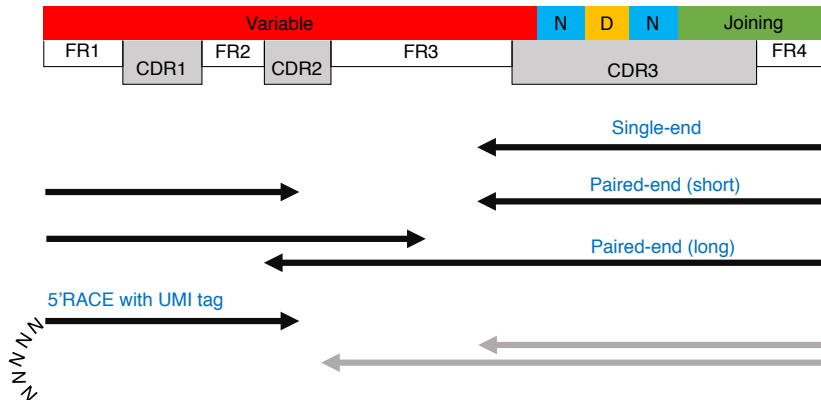


In total there are four framework (FRs) and three complementarity determining regions/loops (CDRs).

The likely functions of these regions are:

- ▶ FR regions maintain TCR secondary structure and (possibly) play role in MHC binding
- ▶ CDR1,2 are germline encoded and play role in antigen recognition, as well as (possibly) MHC binding
- ▶ CDR3 plays a major role in antigen recognition and is extremely variable

TCR repertoire sequencing



An example of a RepSeq dataset

After all pre-processing steps:

- ▶ Read grooming (filtering, etc)
- ▶ UMI-based assembly (for molecular barcoded data)
- ▶ V-D-J mapping and clonotype assembly

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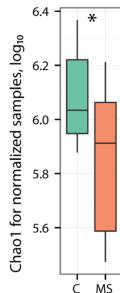
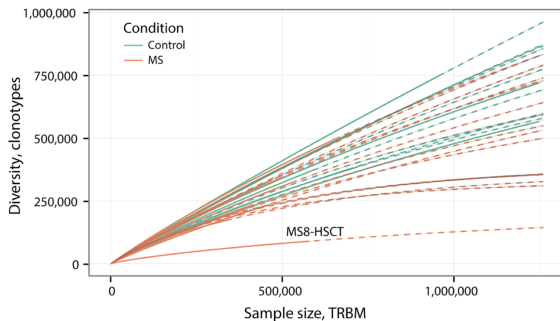
We finally get clonotype frequency tables that look like

Index	Frequency	Count	CDR3AA	V	D	J	CDR3NT
1	1.0%	3913	CSA GG L G STDTQ YF	TRBV20-1	TRBD1	TRBJ2-3	TGCAGT GCTG GGGGGC TCGGTAGCACAGATACGCAGTATTTT
2	0.90%	3440	CAS NSG SSYNEQ FF	TRBV5-1	TRBD2	TRBJ2-1	TGCGCCAGCA ATAG CGGGAGCTCCTACAATGAGCAGTCTTTC
3	0.79%	3021	CSA RQG N Q PQH F	TRBV20-1	TRBD1	TRBJ1-5	TGCAGT GCGC SACAGGGGAATCAGCCCCAGCATTTT
4	0.65%	2490	CASSQ EPG GEQ FF	TRBV4-1	TRBD2	TRBJ2-1	TGCGCCAGCAGCCAAGAGCCGGGGGGGAGCAGTCTTTC
5	0.61%	2336	CASSY GM NTEA FF	TRBV6-6	TRBD2	TRBJ1-1	TGTGCCAGCAGTTACGGGATGAACACTGAAGCTTTCTTT
6	0.52%	1992	CASSQ GGR APHTQ YF	TRBV4-3	TRBD2	TRBJ2-3	TGCGCCAGCAGCCAAGGGGGGAGGGCCCCCATACGCAGTATTTT
7	0.49%	1871	CASSQ SGG S Y EQ YF	TRBV5-1	TRBD1	TRBJ2-7	TGCGCCAGCAGCCA AAAGTCA AGGGGGGTCTACGAGCAGTACTTC
8	0.48%	1847	CASSR PKSGR SGEL FF	TRBV11-2	TRBD2	TRBJ2-2	TGTGCCAGCAGCCGACCCAAGAGCGGGAGAAAGTGGGGAGCTGTTTTTT

Outline

Diversity analysis

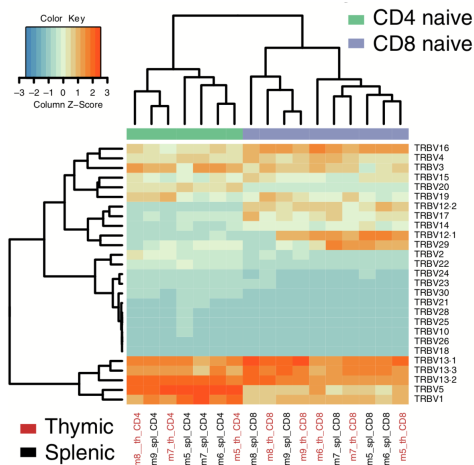
Inspired by species richness/diversity analysis in ecology.
Useful to tell naive T-cell samples from antigen-experienced T-cells containing expanded clones.



Shugay et al. PLoS Comp Biol 2015

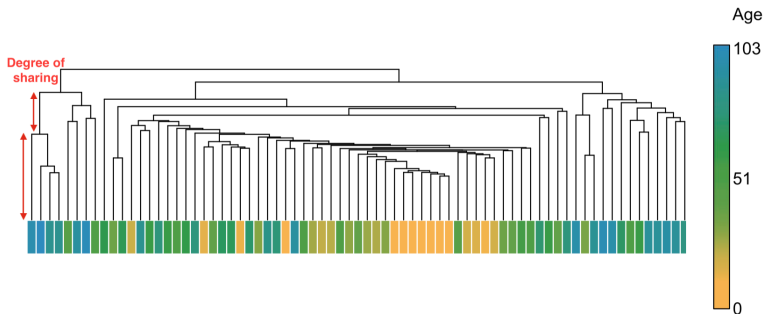
Variable segment usage

Similar to conventional gene expression analysis: segment profile can be useful for distinguishing different subsets of T-cells.



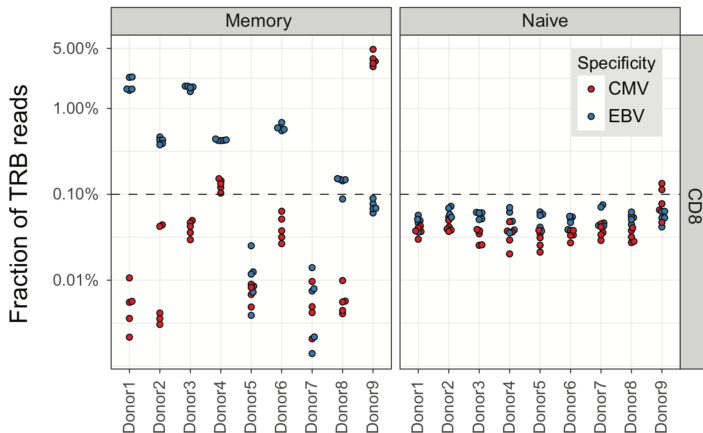
Clonotype sharing

The overlap/co-incidence of hypervariable CDR3 region sequences in different samples. Useful for determining sample origin and comparative analysis of immune repertoires in general.



TCR sequence annotation

Using a curated database of TCRs with known antigen specificity (VDJdb, vdjdb.cdr3.net). Directly searching for specific TCRs/determining the specificity profile of a repertoire.



Outline

Downloading data

Navigate to

`github.com/antigenomics/repseq-annotation-tutorial`
and download the data + code bundle as zip

The screenshot shows the GitHub repository page for `antigenomics / repseq-annotation-tutorial`. The repository is described as "RepSeq data mining basics in R". It has 17 commits, 1 branch, 0 releases, 1 contributor, and is licensed under CC-BY-SA-4.0. The "Clone or download" button is highlighted with a red circle.

antigenomics / repseq-annotation-tutorial

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RepSeq data mining basics in R

Add topics

17 commits 1 branch 0 releases 1 contributor CC-BY-SA-4.0

Branch: master New pull request

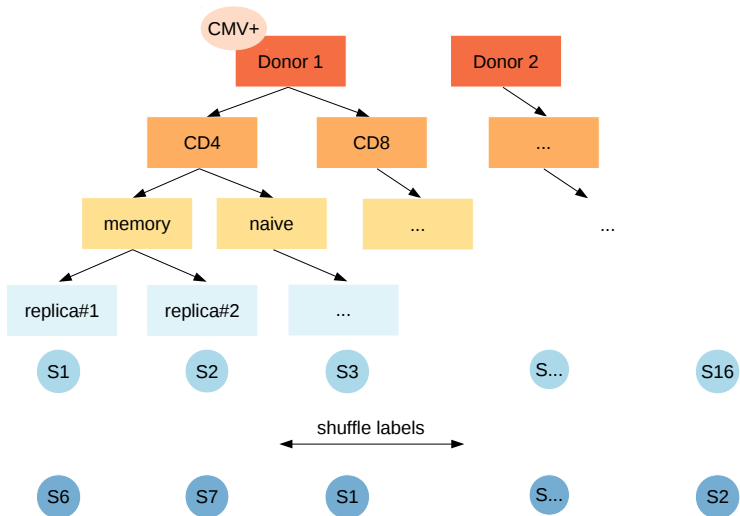
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mikeshh 2prev Latest commit 7a11e5d 3 minutes ago

datasets	Shuffle datasets, add PDF	14 days ago
slides	2prev	42 minutes ago
.gitignore	Slides WIP	14 days ago
LICENSE	Add license	14 days ago
README.md	readme upd	33 minutes ago
samples.png	upd	44 minutes ago

Dataset layout

Datasets were generated as shown in the figure below



Executing R code

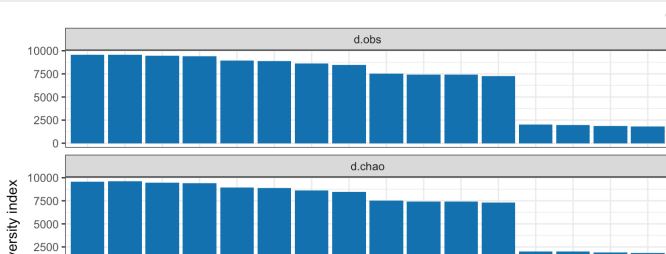
Open the tutorial1.Rmd in RStudio, it can be found in the root folder of the bundle.

```
108 Plot diversity values
109
110 ~~~{r message=FALSE}
111 diversity %>%
112   melt %>%
113   # set what values we are going to plot
114   # fct_reorder reorders sample id by value
115   ggplot(aes(x=fct_reorder2(sample_id, variable, value), y=value)) +
116   # we'll make a bar plot
117   geom_bar(stat = "identity", fill = "#0570b0") +
118   # show each index on different subplot
119   facet_wrap(~variable, scales = "free_y", ncol = 1) +
120   xlab("") + ylab("Diversity index") +
121   theme_bw()
122 ~~~
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Outline

Interactive part



Outline

The assignment

Using the analysis results we've obtained we need to assign feature labels to each sample. Namely, you need to fill the table with the following structure:

sample	donor	subset	phenotype	CMVstatus
s1	D1	CD4	memory	CMV-
s2	D2		naive	CMV+
s3	D1	CD8	naive	CMV-
...

Details

Table filling rules:

- ▶ Column names should match those on previous slide
- ▶ Sample id should be one of $s_1..s_{16}$
- ▶ Two distinct donor IDs should be used, naming doesn't matter
- ▶ Subset should be either **CD4** or **CD8**
- ▶ Phenotype should be either **memory** or **naive**
- ▶ CMV status should be either **CMV+** or **CMV-**
- ▶ Unknown/ambiguous fields should be left blank

A hint

While you can unambiguously assign CD4/8 and memory/naive labels, as well as point out biological replicates of the same sample, assigning donor labels is tricky.

First, it is impossible to link CD4-CD8 cells of the same donor. Same for CMV status, that is unambiguous only for CD8+ memory T-cells. Therefore I expect that you mark donors in the way they will distinguish samples/replicas coming from the same and different donors.

I.e. there is no problem if donor labels are swapped between CD4 and CD8 T-cells as far as they point to distinct donors for CD4 or CD8 T-cells coming from different donor and the same donor for replicas.

Feedback

Send me filled tables to :

- ▶ As plain text tab-delimited files
- ▶ Mail title should start with .
- ▶ Attachment name should be in format.

Thanks for your attention!

These slides and a PDF file containing compiled analysis results can be found in `slides/` and `root` folders of the data and code bundle.