

# HIGH PERFORMANCE RESEARCH COMPUTING

## Introduction to NGS Data Analysis



High Performance  
Research Computing  
DIVISION OF RESEARCH

Fall 2024

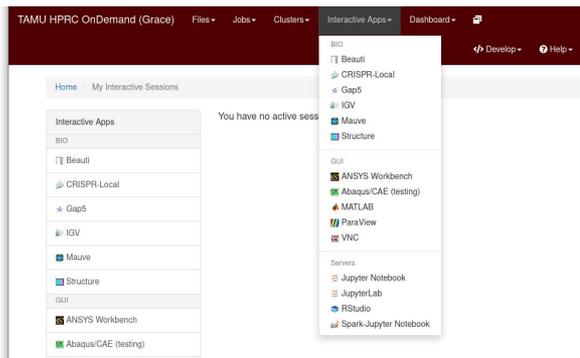


# Introduction to NGS

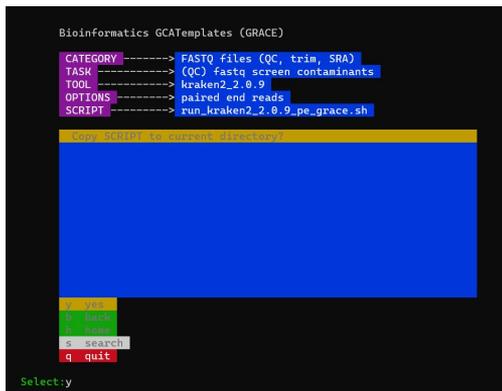
- HPRC Cluster Utilities
- NGS Technology
- NGS Tools on Grace
- Quality Control (QC)
- Template Job Scripts
- Visualize BAM Alignment Files
- Sequence Variant Calling
- RNA-seq
- ChIP-seq
- Biocontainers

# Options for Running Bioinformatics Tools

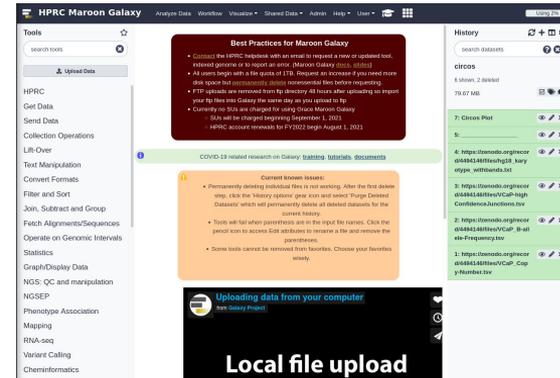
## HPRC Portal



## Unix command line



## HPRC Maroon Galaxy



- [portal-grace.hprc.tamu.edu](http://portal-grace.hprc.tamu.edu)
- Access is web-browser-based
- All HPRC software tools are available either as a GUI or via Unix command line
- Can access Unix command line
- Best for GUI apps
  - RStudio
  - IGV
- Need to learn Unix and Slurm
- Bioinformatics template scripts available
- GUI software is not very responsive interactively
- Need SSH client on your Windows computer such as MobaXterm or use the HPRC portal
- Access is web-browser-based
- First [apply](#) for an HPRC account then request a Galaxy account
- Can request HPRC to add tools from the [usegalaxy.org](http://usegalaxy.org)
- [toolshed](#) or create a custom tool

# Using SSH - MobaXterm (on Windows) to Connect to Grace

click "Session" to begin

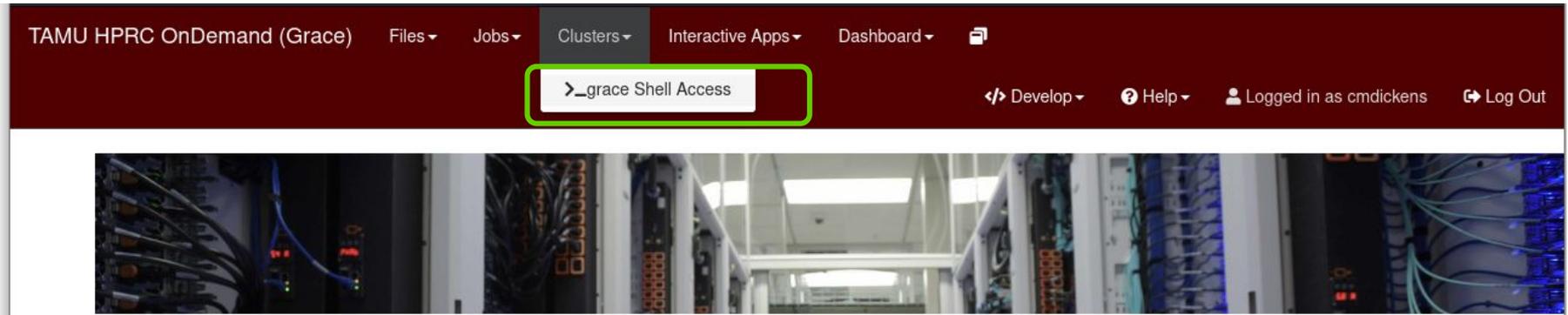
- X11 is enabled by default in MobaXterm
- Use "ssh -X" when using the terminal to enable X11

X11 enables you to view images when using the terminal

<https://hprc.tamu.edu/kb/Helpful-Pages/#mobaxterm>

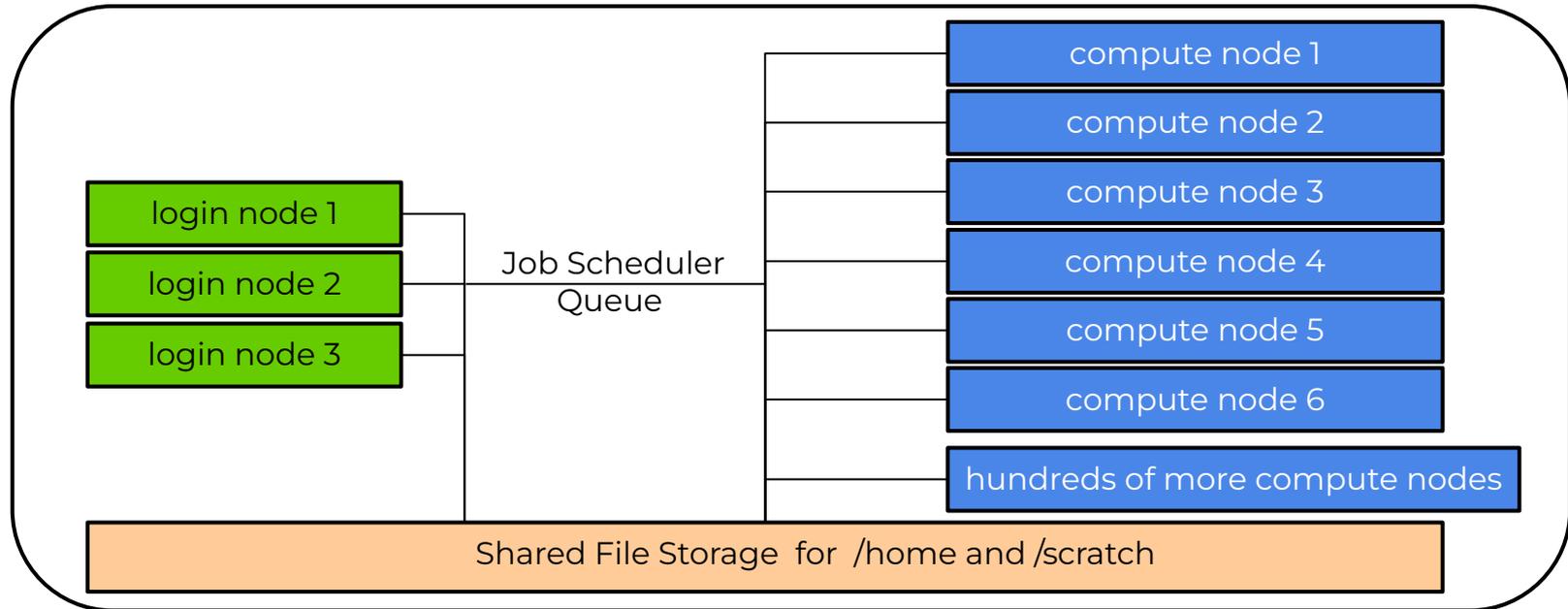
# Connect using the HPRC portal

[portal-grace.hprc.tamu.edu](https://portal-grace.hprc.tamu.edu)



- There are no SUs charged for using the Shell Access since an actual job is not launched.
- Interactive Apps launch jobs and charge SUs.

# HPC Diagram



## login nodes are for:

- file manipulation and job script preparation
- software installation and testing
- short tasks (< 60 minutes and max 8 cores)
  - also be aware of amount of memory utilized

## compute nodes are for:

- computational jobs which can use up to 48 cores and/or up to 360GB memory per Grace compute node.
- all jobs running > 60 minutes

# HPRC Cluster Utilities

A number of cluster utilities are available to help you query resources at the command line such as available nodes, GPUs, cores, memory, template job scripts and shared conda and Python environments.

<code>myjob</code>	<code>gpuavail</code>
<code>maxconfig</code>	<code>cpuavail</code>
<code>gcatemplates</code>	<code>envsavail</code>
<code>jobstats</code>	<code>venvavail</code>
<code>toolchains</code>	<code>maintenance</code>

use the `-h` or `--help` flag with any utility to see available options

# Show Your Job Details using myjob

```
[userid@grace ~]$ myjob 11760808
```

```
    Job ID: 11760808
    Cluster: grace
    User/Group: userid/userid
    State: COMPLETED (exit code 0)
    Partition: cpu
    Node Count: 1
    NodeList: c098
    Cores per node: 24
    CPU Utilized: 01:01:54
    CPU Efficiency: 0.57% of 7-12:11:12 core-walltime
    Submit time: 2024-10-21 15:20:05
    Start time: 2024-10-21 15:20:26
    End time: 2024-10-21 22:50:54
    Job Wall-clock time: 07:30:28
    Memory Utilized: 37.08 GB
    Memory Efficiency: 20.60% of 180.00 GB
    Job Name: parafold-cpu
    Job Submit Directory: /scratch/user/userid/af_demo
    Submit Line: sbatch run_parafold_2.0_alphafold_2.3.2_a100_monomer_ptm_grace.sh
```

use the -h flag to view usage  
myjob -h

# PENDING Job due to a Scheduled Maintenance

```
[userid@grace ~]$ myjob 1320633
```

```
    Job ID: 1320633
    Cluster: faster
    User/Group: userid/userid
    Account: 123456789101
    State: PENDING
    Reason: ReqNodeNotAvail, Reserved for maintenance
    Submit time: 2024-10-14 10:09:59
    Partition: cpu
    Node Count: 1
    NodeList: None assigned
    Cores: 1
    Note: Efficiency not available for jobs in the PENDING state.
    Job Name: picard
    Job Submit Directory: /scratch/user/userid/myproject/picard
    Submit Line: sbatch run_bwa_samtools_pilon_faster.sh
    Note: job is PENDING due to runtime overlapping with maintenance window.
    Note: maintenance will begin in 22 hours, and 49 minutes.
```

# PENDING Job due to Partition Time Limit

```
[userid@grace ~]$ myjob 11805612
```

```
Job ID: 11805612  
Cluster: grace  
User/Group: userid/userid  
Account: 132787216126  
State: PENDING
```

```
Reason: PartitionTimeLimit  
Submit time: 2024-10-23 13:14:58  
Partition: bigmem  
Node Count: 1
```

```
NodeList: None assigned  
Cores: 1
```

```
Note: Efficiency not available for jobs in the PENDING state.
```

```
Job Name: my_job
```

```
Job Submit Directory: /scratch/user/userid/myproject/canu
```

```
Submit Line: sbatch run_canu_bigmem_grace.sh
```

```
Note: The bigmem Partition has a maximum of 2-00:00:00 but the job script has 7-00:00:00
```

```
Note: Use the 'scancel 11805612' command to cancel this job and reconfigure your bigmem  
job script to use a maximum of 2-00:00:00
```

```
Note: Use the 'sinfo' command to see all partition time limits.
```

# Viewing Maximum Available Resources

The **maxconfig** command will show the recommended Slurm parameters for the maximum available resources (cores, memory, time) per node for a specified accelerator or partition (default Grace partition: long)

```
[username@grace ~]$ maxconfig

Grace partitions:  short medium long xlong vnc gpu bigmem special gpu-a40
Grace GPUs in gpu partition:  a100:2 a40:3 rtx:2 t4:4

Showing max parameters (cores, mem, time) for partition long

CPU-billing * hours * nodes =  SUs
          48 *   168 *     1 = 8,064

#!/bin/bash
#SBATCH --job-name=my_job
#SBATCH --time=7-00:00:00
#SBATCH --nodes=1          # max 64 nodes for partition long
#SBATCH --ntasks-per-node=1
#SBATCH --cpus-per-task=48
#SBATCH --mem=360G
#SBATCH --output=stdout.%x.%j
#SBATCH --error=stderr.%x.%j
```

# Viewing Maximum Available Resources

See the recommended Slurm parameters for requesting 1 x A100 GPU with  $\frac{1}{2}$  the total CPUs and memory since there are 2 x A100s per node.

```
[username@grace ~]$ maxconfig -g a100 -G 1

Grace partitions:  short medium long xlong vnc  gpu  bigmem  special  gpu-a40
Grace GPUs in gpu partition:  a100:2  a40:3  rtx:2  t4:4

Showing 1/2 of total cores and memory for using 1 x a100 GPU

(CPU-billing + (GPU-billing * GPU-count)) * hours * nodes =  SUs
(          25 + (          72 *          1)) * 96 *  1 = 9,312

#!/bin/bash
#SBATCH --job-name=my_job
#SBATCH --time=4-00:00:00
#SBATCH --nodes=1          # max 32 nodes for partition gpu
#SBATCH --ntasks-per-node=1
#SBATCH --cpus-per-task=24
#SBATCH --mem=180G
#SBATCH --gres=gpu:a100:1
#SBATCH --output=stdout.%x.%j
#SBATCH --error=stderr.%x.%j
```

<https://hprc.tamu.edu/kb/Software/useful-tools/maxconfig>

# Checking GPU Configuration & Availability on ACES

- Use the command line (shell) to see the current GPU configuration and availability.
- The GPU configuration can change since ACES is a composable resource cluster.
- If there are no GPUs in the AVAILABILITY output, it means that a GPU job that you submit may take a while to start.
- AlphaFold does not support running on PVC GPUs.

```
[username@grace ~]$ gpuavail
```

CONFIGURATION	
NODE	NODE
TYPE	COUNT
-----	
gpu:a100:2	100
gpu:a40:3	15
gpu:rtx:2	9
gpu:t4:4	8

		AVAILABILITY			
NODE	GPU	GPU	GPUs	CPUs	GB MEM
NAME	TYPE	COUNT	AVAIL	AVAIL	AVAIL
-----					
g001	a100	2	2	48	360
g002	a100	2	2	48	360
g003	a100	2	2	48	360
g004	a100	2	2	48	360
g005	a100	2	1	24	180

<https://hprc.tamu.edu/kb/Software/useful-tools/gpuavail>

# Check non-GPU node Availability

Use the `cpuavail` command to see non-GPU nodes readily available for jobs.

```
[username@grace ~]$ cpuavail
```

CONFIGURATION		AVAILABILITY		
NODE TYPE	NODE COUNT	NODE NAME	CPUs AVAIL	GB MEM AVAIL
-----	-----	-----	-----	-----
CPU-only	808	c001	16	330
GPU	132	c005	16	107
		c006	16	104
		c007	16	104
		c008	16	104
		c009	16	104
		c010	16	104
		c011	16	104
		c013	16	104
		c014	16	104
		c015	16	104
		c016	16	104

<https://hprc.tamu.edu/kb/Software/useful-tools/cpuavail>

# Cluster maintenance

- You can use the maintenance command to see if there is a scheduled cluster maintenance.

```
[username@grace ~]$ maintenance
```

```
The scheduled 11 hour Grace maintenance will start in:
```

```
3 days 16 hours 41 minutes
```

```
Scheduled jobs will not start if they overlap with this maintenance window.
```

A 7-day job submitted at the time of the above message will remain queued and will not start until after the maintenance is complete.

# Next Generation Sequencing Technologies

# Illumina Sequencing Technology



[iSeq 100 System](#)



[MiniSeq System](#)



[MiSeq System](#)



[MiSeq i100 Series<sup>a</sup>](#)



[NextSeq 550 System](#)



[NextSeq 1000 and 2000 Systems](#)



[NextSeq 1000 and 2000 Systems](#)



[NovaSeq 6000 System](#)



[NovaSeq X Series](#)

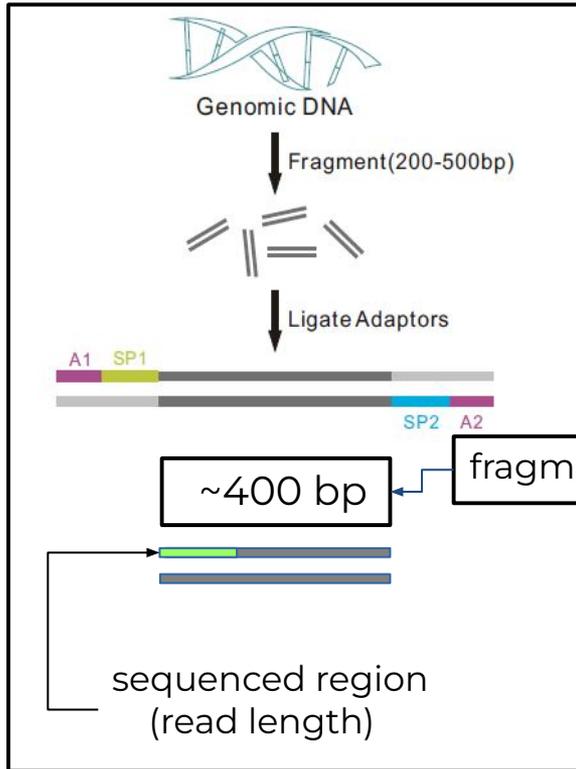
images are not to scale

<http://www.illumina.com/systems/sequencing-platforms.html>

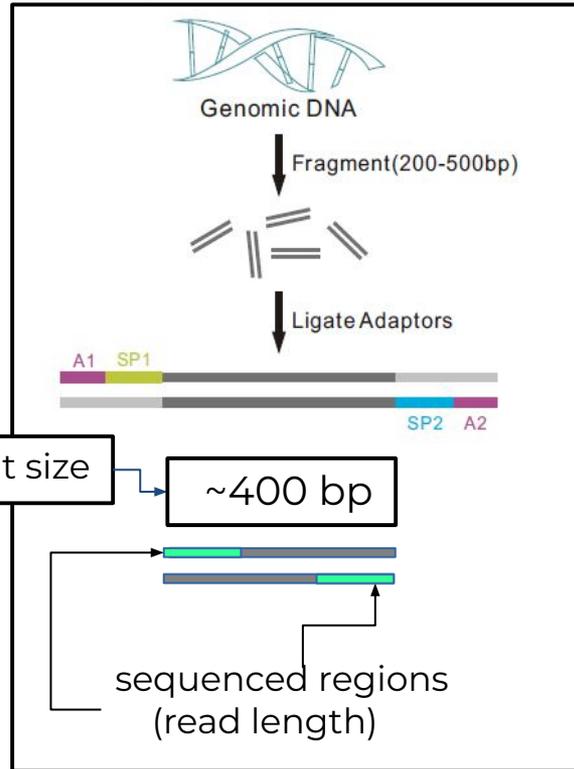
# Illumina Sequencing Libraries

illumina.com

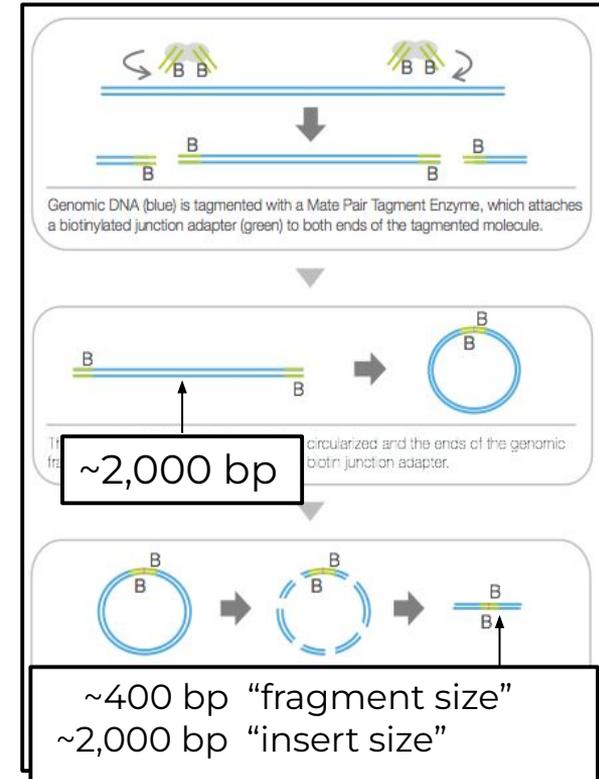
## single end



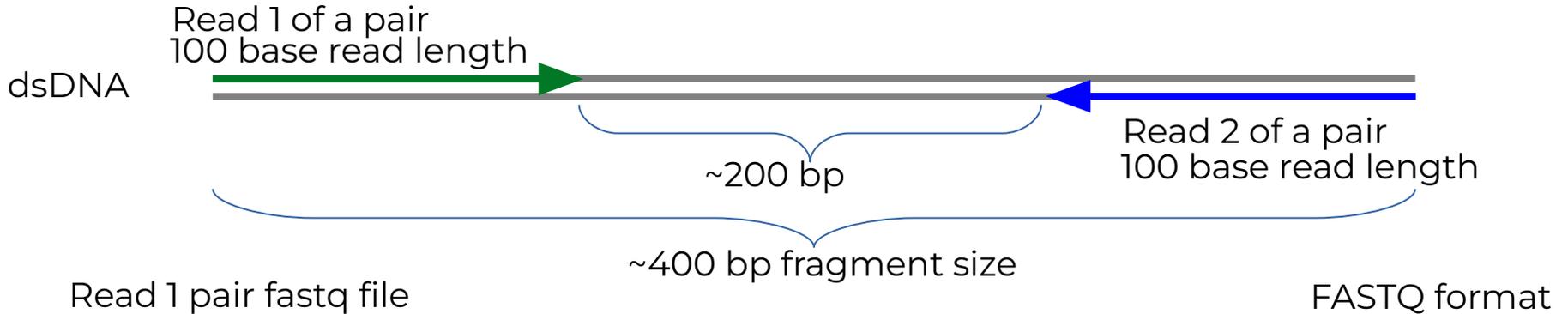
## paired ends



## mate pairs



# Paired End Reads

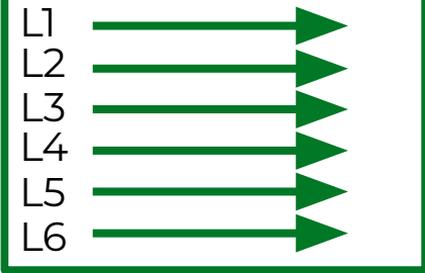
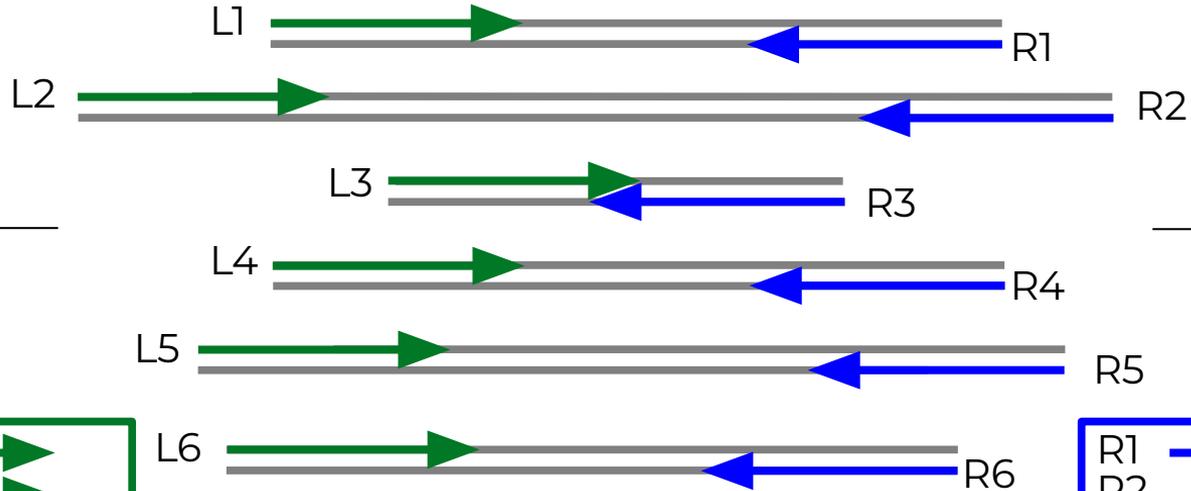


```
@M00861:1:000000000-A36BE:1:1101:14650:1529 1:N:0:8
TTCTTAAAAATACCATAAAAAGGCTTAAACTTGCCATTTACGACGGATTAATTCCAACCTCTTTTCGGCTATCTTCATCTTTTAAGGTTAAATGACTCATAACGG
+
FFFHBFFHHIIIIIIHFHHCGEFGHHIHHHIHD/?DGGHHH@DEB,5EGHGHHIIHIF?FGGHHCCBFDGHFHDGHGFFFFGDFHH?DFHDFHHHFHFHFHHH
```

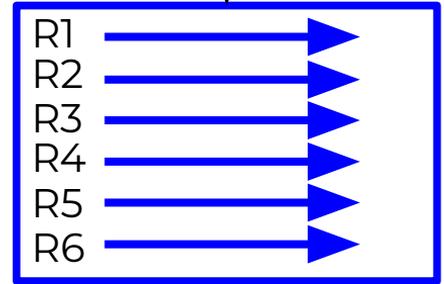
Read 2 pair fastq file

```
@M00861:1:000000000-A36BE:1:1101:14650:1529 2:N:0:8
ACTAAAAATCAATTTTATCAATTTCAAGCTCTACCTTATTTACTCATTTATTTTAGTGATGGCCACTTTAATAAAAAATATTGGTAGCATATTTTGCAATAGCGG
+
BFFHIIHHHFHHDGHIHHIHHHGHHHHHFFHDFHHIHI I IHIHDFHHHIHI I IH=AAFHII IHFGFHHHHHGGHHIHHFGFFFEGGHHHDGHHH/CGHIFHHH
```

# Maintain Read Pair Order



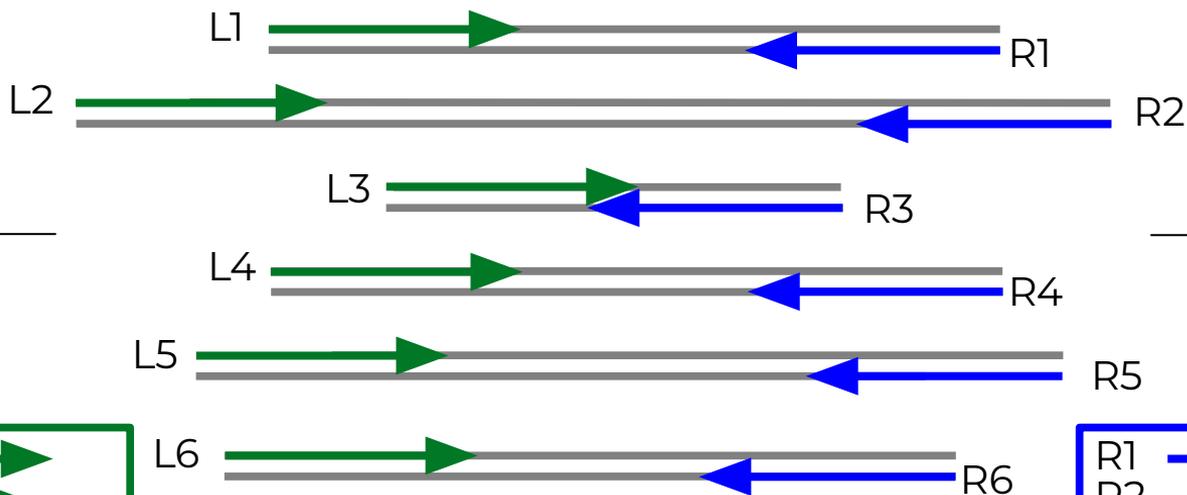
Left Read 1 paired end fastq file



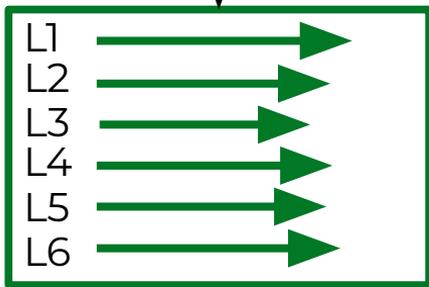
Right Read 2 paired end fastq file

DNA Fragment lengths will be different but sequence reads may all be the same length

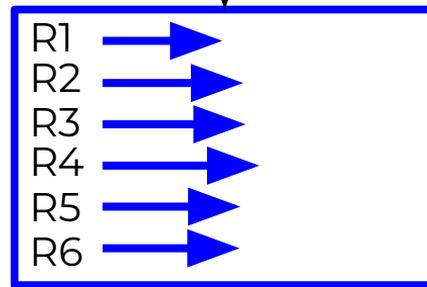
# MiSeq Can Perform Initial QC Trimming



DNA Fragment lengths will be different but  
sequence reads can have different lengths



Left Read 1 paired end fastq file

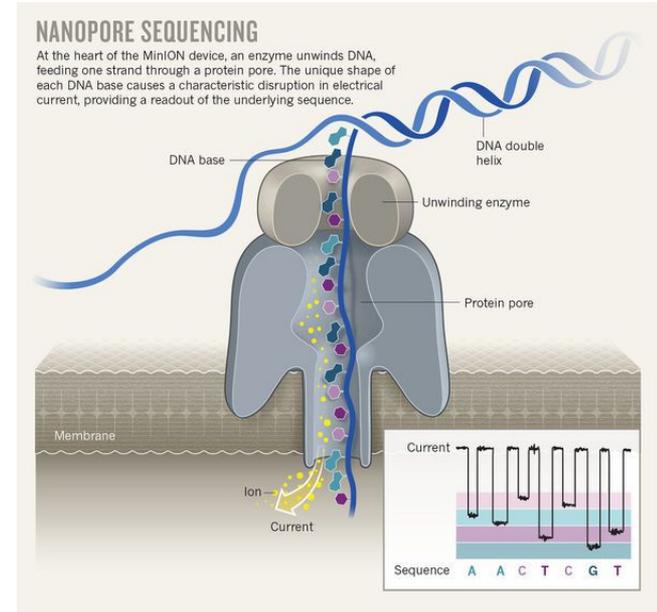


Right Read 2 paired end fastq file

# Oxford Nanopore Long Read Sequencing



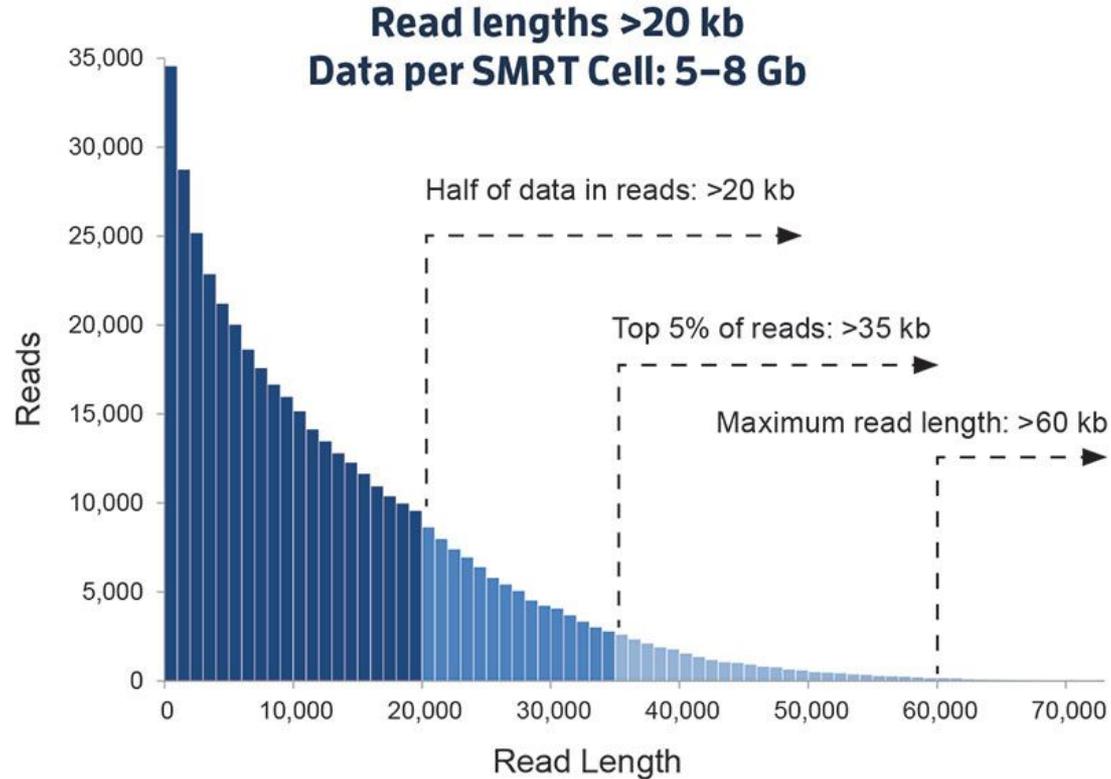
Oxford Nanopore Technologies (ONT)



<http://blogs.nature.com>  
TechBlog: The nanopore toolbox  
16 Oct 2017 | 12:00 GMT | Posted by Jeffrey Perkel

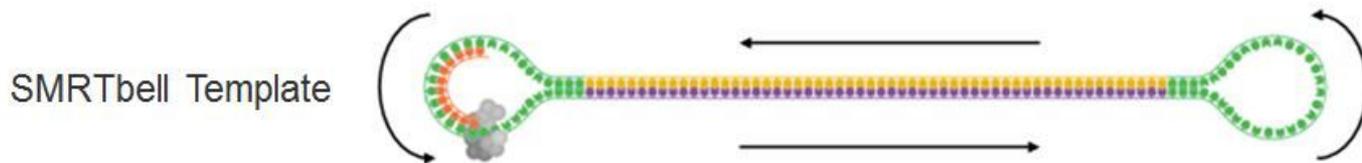
# PacBio Long Read Sequencing

Sequel Sequence



[pacb.com](http://pacb.com)

# PacBio Long Read Sequencing



+ Strand yellow  
- Strand purple

Shorter DNA fragment (5kb) equals more subreads and higher accuracy than longer (60kb)



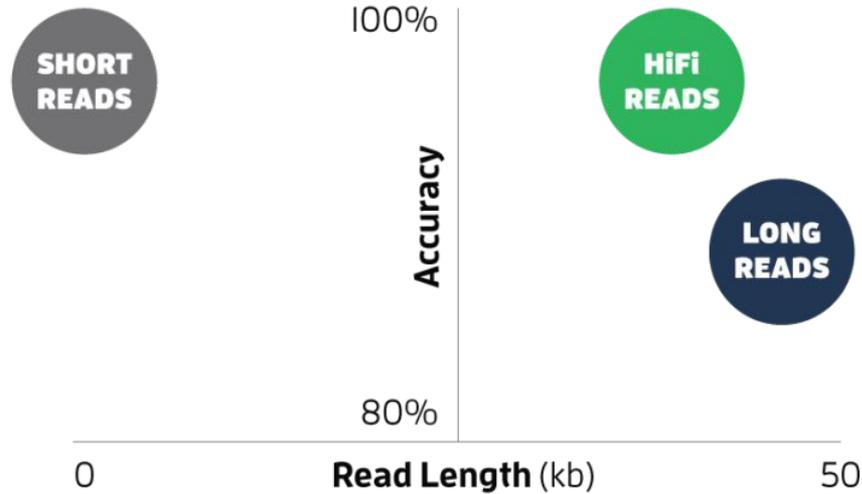
Circular Consensus Sequence (Read of Insert)

```
m54001_160302_121501.subreads.bam  
1 | 2 | 3 | 4 | 5 |
```

[1] "m" = movie  
[2] Instrument Serial Number  
[3] Time of Run Start ('yymmdd\_hhmmss')  
[4] File Descriptor  
[5] File Extension

[pacb.com](http://pacb.com)

# PacBio HiFi Reads



<https://www.pacb.com/blog/hifi-webinar>

- HiFi reads are not subreads since they are already error corrected
- HiFi utilize single-molecule consensus rather than multiple-molecule consensus

# NGS Tools on Grace

# Where to Find NGS Tools

- Search TAMU HPRC Documentation
  - <https://hprc.tamu.edu/kb/Software/Bioinformatics>
- Type any the following Unix commands to see which tools are already installed on Grace (replace toolname with sw name)
  - `module spider toolname` (not case sensitive, but read the entire output)
  - `module key assembly` (some modules may be missed because this searches tool descriptions)
- Some tools such as qiime2 are available with Anaconda and do not show up with the module command
  - use the `envsavail` command to see available conda envs
- If you are unable to find a tool that you want installed on Grace, send an email with the URL link to: [help@hprc.tamu.edu](mailto:help@hprc.tamu.edu)
- Useful websites: [long-read-tools.org](http://long-read-tools.org)

# PacBio Sequencing Tools

- Sequence Alignments
  - Minimap2
- Genome Assembly
  - Canu: PacBio long read assembler
    - grid mode not supported on HPRC clusters
  - Unicycler: bacterial genomes
  - wtdbg2: 10x faster than Canu
    - assembly is very close but not as complete as Canu
  - Flye: PacBio and ONT reads; metagenome also available
- Improve draft assemblies
  - Purge\_Haplotigs
  - Circlator

[https://hprc.tamu.edu/kb/Software/Bioinformatics/PacBio\\_tools](https://hprc.tamu.edu/kb/Software/Bioinformatics/PacBio_tools)

# Tool Suites

- SMRT-Link (PacBio)
  - contains command line versions of additional SMRT Analysis tools
  - PacBio's open-source SMRT Analysis software suite is designed for use with Single Molecule, Real-Time (SMRT) Sequencing data.

bam2fasta	bam2fastq	bamsieve	bax2bam	blasr	ccs	cleric	cromwell
daligne	r	daligner_p	datander	dataset	dazcon	DB2Falcon	DB2fasta
DBdump	DBdust	DBrm	DBshow	DBsplit	DBstats	dexta	falconc
falconcpp	fasta2DB	fuse	gcpp	HPC.daligner	HPC.REPmask		HPC.TANmask
ipdSummary	ipython	ipython2	isoseq3	juliet	julietflow	LA4Falcon	LA4Ice
laa	laagc	LAmerge	LAsort	lima	minimap2	motifMaker	pbalign
pbcromwell	pbdagcon	pbindex	pbmm2	pbservice	pbsv	pbvalidate	ra
REPmask	samtools	sawriter	summarizeModifications		TANmask	undexta	womtool

**module spider SMRT-Link**

# Genome Hybrid Assemblers (Long-reads + Illumina reads)

- SPAdes
  - subreads as input files
  - no need to correct subreads with short reads prior to assembly
  - uses long reads for gap closure and repeat resolution
- MaSuRCA
  - All long-reads must be in a single fasta file
- Unicycler
  - assembly pipeline for bacterial genomes
  - circularises replicons without the need for a separate tool like Circulator

# Grace Software Toolchains

- search for module names using module spider

```
module spider bowtie2
```

- use module spider with module name for details on how to load module

```
module spider Bowtie2/2.4.2
```

- read output to see which other module(s) to load first

```
module load GCC/10.2.0 Bowtie2/2.4.2
```

show loaded modules

```
module list
```

- see what other modules are compatible with the loaded module(s)

```
module avail samtools
```

- load additional compatible modules

```
module load SAMtools/1.11
```

- unload all loaded modules

```
module purge
```

# Toolchains

- See a short table of compatible toolchains and python versions

## toolchains

Toolchain	=	GCC version	& MPI version		Available Python version *
foss/2023b	=	GCC/13.2.0	& OpenMPI/4.1.6		Python/3.11.5
foss/2023a	=	GCC/12.3.0	& OpenMPI/4.1.5		Python/3.11.3
foss/2022b	=	GCC/12.2.0	& OpenMPI/4.1.4		Python/3.10.8
foss/2022a	=	GCC/11.3.0	& OpenMPI/4.1.4		Python/3.10.4
foss/2021b	=	GCC/11.2.0	& OpenMPI/4.1.1		Python/3.9.6
foss/2021a	=	GCC/10.3.0	& OpenMPI/4.1.1		Python/3.9.5
foss/2020b	=	GCC/10.2.0	& OpenMPI/4.0.5		Python/3.8.6
foss/2020a	=	GCC/9.3.0	& OpenMPI/4.0.3		Python/3.8.2
foss/2019b	=	GCC/8.3.0	& OpenMPI/3.1.4		Python/3.7.4
foss/2018b	=	GCC/7.3.0-2.30	& OpenMPI/3.1.1		Python/3.7.0
intel/2023b	=	GCCcore/13.2.0	& impi/2021.10.0		Python/3.11.5
intel/2022a	=	GCCcore/11.3.0	& impi/2021.6.0		Python/3.10.4
intel/2022.12	=	GCCcore/12.2.0	& impi/2021.8.0		Python/3.10.8
intel/2022.09	=	GCCcore/12.2.0	& impi/2021.7.0		Python/3.10.8
intel/2022.05	=	GCCcore/11.3.0	& impi/2021.6.0		Python/3.10.4
intel/2022.00	=	GCCcore/11.2.0	& impi/2021.5.0		Python/3.9.6
intel/2021b	=	GCCcore/11.2.0	& impi/2021.4.0		Python/3.9.6
intel/2021a	=	GCCcore/10.3.0	& impi/2021.2.0		Python/3.9.5
intel/2020b	=	GCCcore/10.2.0	& impi/2019.9.304		Python/3.8.6
intel/2020a	=	GCCcore/9.3.0	& impi/2019.7.217		Python/3.8.2
intel/2019b	=	GCCcore/8.3.0	& impi/2018.5.288		Python/3.7.4

Use 'toolchains -a' to show all toolchains

\* Available but not loaded; you will need to also load this module to use it.

Do not load the foss and the intel Toolchains at the same time.

Do not load Toolchains that have a different name/year at the same time.

'module load foss/2023b' will also load GCC/13.2.0, GCCcore/13.2.0 and OpenMPI/4.1.6

'module load intel/2023a' will also load GCCcore/12.3.0 and impi/2021.9.0

'module load GCC/13.2.0' will also load GCCcore/13.2.0 but not foss/2023b or OpenMPI/4.1.6

'module load GCCcore/13.2.0' will only load GCCcore/13.2.0

The toolchains default is to show only foss and intel toolchains. Use 'toolchains -a' to see all toolchains

# Use \$TMPDIR Whenever Possible

- Use the \$TMPDIR if the application you are running can utilize a temporary directory for writing temporary files which are deleted when the job ends
- A temp directory (**\$TMPDIR**) is automatically assigned for each job which uses the local disk on the compute node—not the /scratch shared file system
  - Especially useful when a computational tool writes tens of thousands of temporary files which are deleted when the job is finished and are not needed for the final results
  - This is useful since files on **\$TMPDIR** will not count against your file quota
  - Don't use **\$TMPDIR** if your software uses temporary files for restarting where it left off if it should stop before completion
  - Will significantly speed up an mpiBLAST job

```
java -Xmx350g -jar $EBROOTPICARD/FastqToSam.jar TMP_DIR=$TMPDIR \  
FASTQ=$pe1_1 FASTQ2=$pe1_2 OUTPUT=$outfile SAMPLE_NAME=$sample_name \  
SORT_ORDER=$sort_order MAX_RECORDS_IN_RAM='null'
```

# Quality Control (QC)

# QC Evaluation

- Use FastQC to visualize quality scores
  - Displays quality score distribution of a subset of ~200,000 reads
    - Input is a fastq file or files
    - Can disable grouping (binning) of sequence regions
  - Will alert you of poor read characteristics
  - Can be run as a GUI or a command line interface

```
module load FastQC/0.11.9-Java-11
```

- FastQC will process using one CPU core per file
  - If there are 10 fastq files to analyze and 4 cores are used, 4 files will start processing and 6 will wait in a fastqc queue
  - If there is only one fastq file to process then using 10 cores does not speed up the process

# Digital Normalization for Assembly

- Reduce memory requirements by reducing the number of redundant sequence reads if you have a very high sequencing coverage (> 200x)
- Used for genome and transcriptome assembly, not variant calling or quantitative analysis (ChIP-seq, RNA-seq for expression profiling)
- Trinity 2.4.0+ automatically normalizes reads to a depth of 50x using a modified version of seqtk
- The **bbnorm.sh** script in BMap can normalize reads
  - use reformat.sh to subsample

`module spider BMap`

# Template Job Scripts

# GCATemplates

## Genomic Computational Analysis Templates

**gcatemplates**

- GCATemplates is a collection of template job scripts for each of the HPRC clusters.
- The template scripts are configured with example input files and can be run without changes to get an idea of how the tool and job scheduling work
- Update the template script as needed for larger datasets, different option values or additional options

```
BIOINFORMATICS GCATemplates (GRACE)

CATEGORY
1. FASTA files
2. FASTQ files (QC, trim, SRA)
3. Genome assembly
4. Metagenomics
5. PacBio tools
6. Phylogenetics
7. Population genetics
8. Protein tools
9. RNA-seq
10. SNPs & indels
11. Sequence alignments
12. Simulate data

s search
q quit

Select:2
```

<https://hprc.tamu.edu/kb/Software/useful-tools/GCATemplates>

# Access GCATemplates Scripts from the HPRC KnowledgeBase

The screenshot shows the Texas A&M HPRC KnowledgeBase interface. The top navigation bar includes the HPRC logo, the text "Texas A&M HPRC", and a search bar. Below the navigation bar, there are links for Home, Quick Start, User Guides, Software, Helpful Pages, and FAQ. The main content area is titled "NGS: Sequence QC" and is divided into three columns. The left column is a sidebar menu with categories like Software, Bioinformatics, and Bioinformatics Tool Categories. The middle column contains a list of sub-sections: Evaluation, FastQC, GCATemplates, and a search bar. Under "GCATemplates", there is a link for "Grace" which is highlighted with a green arrow. A callout box with a green border and text "Click to see template script on github" points to this link. The right column is a "Table of contents" with a list of links including Evaluation, FastQC, RNA-SeQC, KmerGenie, Qualimap, Screen Reads, FastQScreen, Trim, Trimmomatic, Cutadapt, Sequencing Error Correction, Quake, and Lighter. Below the screenshot, there is a blue URL: [https://hprc.tamu.edu/kb/Software/Bioinformatics/Sequence\\_QC](https://hprc.tamu.edu/kb/Software/Bioinformatics/Sequence_QC)

# Finding NGS Job Template Scripts Using GCATemplates on HPRC Clusters

```
mkdir $SCRATCH/ngs_class
```

```
cd $SCRATCH/ngs_class
```

```
gcatemplates
```

For practice, we will copy a template file

- Select #2 then find the template that contains fastqc
  - or use the search function to find fastqc
- Final step will save a template job script file to your current working directory

Genomic Computational Analysis Templates

```
BIOINFORMATICS GCATemplates (GRACE)

CATEGORY
1. FASTA files
2. FASTQ files (QC, trim, SRA)
3. Genome assembly
4. Metagenomics
5. PacBio tools
6. Phylogenetics
7. Population genetics
8. Protein tools
9. RNA-seq
10. SNPs & indels
11. Sequence alignments
12. Simulate data

s search
q quit

Select:2
```

# Sample GCATemplate Job Script (Grace)

```
#!/bin/bash
#SBATCH --job-name=fastqc          # job name
#SBATCH --time=01:00:00           # max job run time dd-hh:mm:ss
#SBATCH --ntasks-per-node=1       # tasks (commands) per compute node
#SBATCH --cpus-per-task=2         # CPUs (threads) per command
#SBATCH --mem=4G                  # total memory per node
#SBATCH --output=stdout.%j        # save stdout to file (%j is jobid)
#SBATCH --error=stderr.%j        # save stderr to file (%j is jobid)

module purge
module load FastQC/0.11.9-Java-11

<<README
- FASTQC manual: http://www.bioinformatics.babraham.ac.uk/projects/fastqc/Help
README
##### VARIABLES #####
# TODO Edit these variables as needed:
##### INPUTS #####
pe1_1='/scratch/data/bio/GCATemplates/data/miseq/c_dublinsiensis/DR34_R1.fastq.gz'
pe1_2='/scratch/data/bio/GCATemplates/data/miseq/c_dublinsiensis/DR34_R2.fastq.gz'

##### PARAMETERS #####
threads=$SLURM_CPUS_PER_TASK

##### OUTPUTS #####
output_dir='./'

##### COMMANDS #####
fastqc -t $threads -o $output_dir $pe1_1 $pe1_2

<<CITATION
- Acknowledge TAMU HPRC: https://hprc.tamu.edu/research/citations.html
- FastQC: http://www.bioinformatics.babraham.ac.uk/projects/fastqc
CITATION
```

# Sample GCATemplate Job Script (Grace)

```
#!/bin/bash
#SBATCH --job-name=fastqc          # job name
#SBATCH --time=01:00:00           # max job run time dd-hh:mm:ss
#SBATCH --ntasks-per-node=1      # tasks (commands) per compute node
#SBATCH --cpus-per-task=2        # CPUs (threads) per command
#SBATCH --mem=4G                  # total memory per node
#SBATCH --output=stdout.%j       # save stdout to file (%j is jobid)
#SBATCH --error=stderr.%j        # save stderr to file (%j is jobid)

module purge
module load FastQC/0.11.9-Java-11

<<README
- FASTQC manual: http://www.bioinformatics.babraham.ac.uk/projects/fastqc/Help
README
##### VARIABLES #####
# TODO Edit these variables as needed:
##### INPUTS #####
pe1_1='/scratch/data/bio/GCATemplates/data/miseq/c_dublinsiensis/DR34_R1.fastq.gz'
pe1_2='/scratch/data/bio/GCATemplates/data/miseq/c_dublinsiensis/DR34_R2.fastq.gz'

##### PARAMETERS #####
threads=$SLURM_CPUS_PER_TASK

##### OUTPUTS #####
output_dir='./'

##### COMMANDS #####
fastqc -t $threads -o $output_dir $pe1_1 $pe1_2

<<CITATION
- Acknowledge TAMU HPRC: https://hprc.tamu.edu/research/citations.html
- FastQC: http://www.bioinformatics.babraham.ac.uk/projects/fastqc
CITATION
```

These parameters are read by the job scheduler

Load the required module(s) first

This is a section of comments

This is a single line comment and not run as part of the script

This is the command to run the application

# FastQC Exercise

- Use the GCATemplate for FastQC to submit a job evaluating the two sequence files
  - `cat run_fastqc_0.11.9_grace.sh`
  - `sbatch run_fastqc_0.11.9_grace.sh`
  - `squeue --me`
  - `myjob JOBID`
- After your fastqc job is complete, unzip the results file and you can view the results files with the **lynx** and **eog** Unix commands
  - eog requires X11 login; if using the portal, use the Files app to view images `unzip DR34_R1_fastqc.zip`

# FastQC Report Using lynx

```
DR34_R1.fastq.gz FastQC Report (p1 of 4)
FastQC FastQC Report
Wed 9 Mar 2016
DR34_R1.fastq.gz

Summary

* [PASS] Basic Statistics
* [PASS] Per base sequence quality
* [PASS] Per tile sequence quality
* [PASS] Per sequence quality scores
* [FAIL] Per base sequence content
* [PASS] Per sequence GC content
* [PASS] Per base N content
* [WARNING] Sequence Length Distribution
* [PASS] Sequence Duplication Levels
* [WARNING] Overrepresented sequences
* [PASS] Adapter Content
* [FAIL] Kmer Content

[OK] Basic Statistics

Measure                               Value
Filename                               DR34_R1.fastq.gz
File type                               Conventional base calls
Encoding                               Sanger / Illumina 1.9
Total Sequences                         946744
Sequences flagged as poor quality       0
Sequence length                         35-251
%GC                                      39

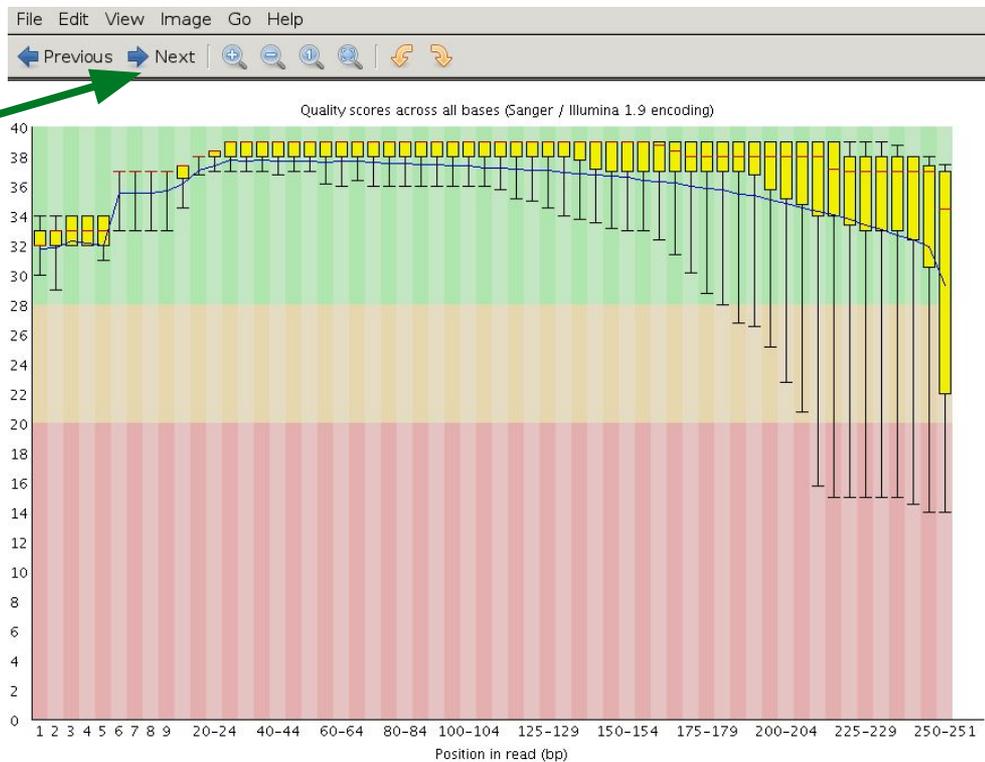
-- press space for next page --
Arrow keys: Up and Down to move. Right to follow a link; Left to go back.
H)elp O)ptions P)rint G)o M)ain screen Q)uit /=search [delete]=history list
```

lynx DR34\_R1\_fastqc.html



# FastQC Output Image Quality Distribution

eog DR34\_R1\_fastqc/Images/per\_base\_quality.png



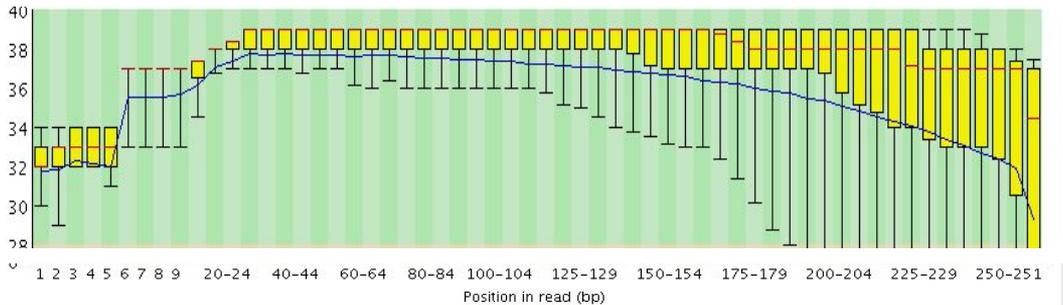
click for the next image in the same directory, or use the left/right arrow keys

Prior to QC trimming

# FastQC Output Image Quality Distribution

FASTQ format

```
@ERR504787.2.1 M00368:15:000000000-A0HKH:1:5:21261:10968-1 length=100
GATCGGAAGAGCACACGTCTGAACTCCAGTCACGATCAGATCTCGTATGCCGTCTTCTGCTTGAAAAA
+ERR504787.2.1 M00368:15:000000000-A0HKH:1:5:21261:10968-1 length=100
==4AD=B8A:+=A: :1<:AE<C3*?F<B???<?:8:6?B*9BD;/638.-'-.@7=) .=A:6?DDDCBB
@ERR504787.3.1 M00368:15:000000000-A0HKH:1:3:12724:25677-1 length=100
GATGTTTTGTTACTGATTGGAACCATGATTGGTGCTTTACTTGGTTTCTTCCTATTTAACCACAAGCCTGC
+ERR504787.3.1 M00368:15:000000000-A0HKH:1:3:12724:25677-1 length=100
BCCFDEFFHHHHHJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
@ERR504787.5.1 M00368:15:000000000-A0HKH:1:2:16161:12630-1 length=100
TATTTTAAGTGACCAAGGAATGACTCCCAATCATGGCTGTATCAACTCCAAAATTTTCTGCAACAGTCGCTG
+ERR504787.5.1 M00368:15:000000000-A0HKH:1:2:16161:12630-1 length=100
CCCCFFFFHHHHHJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```



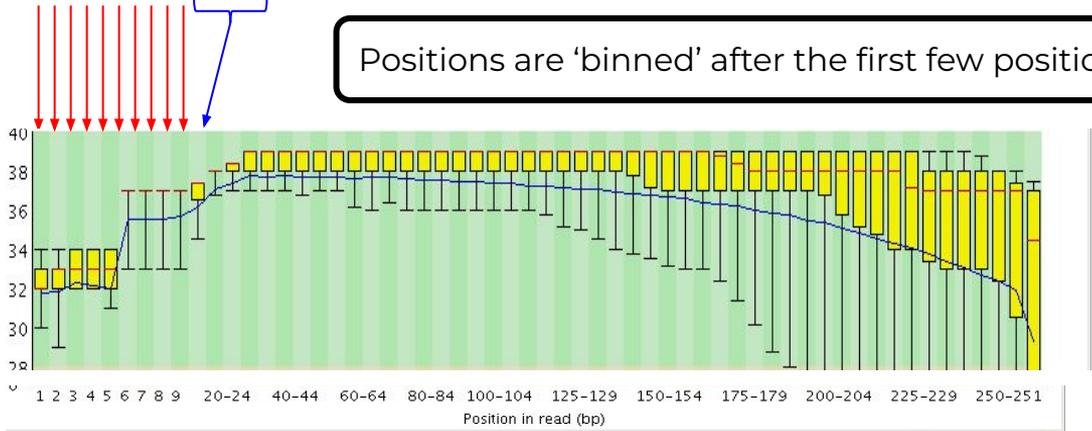


# FastQC Output Image Quality Distribution

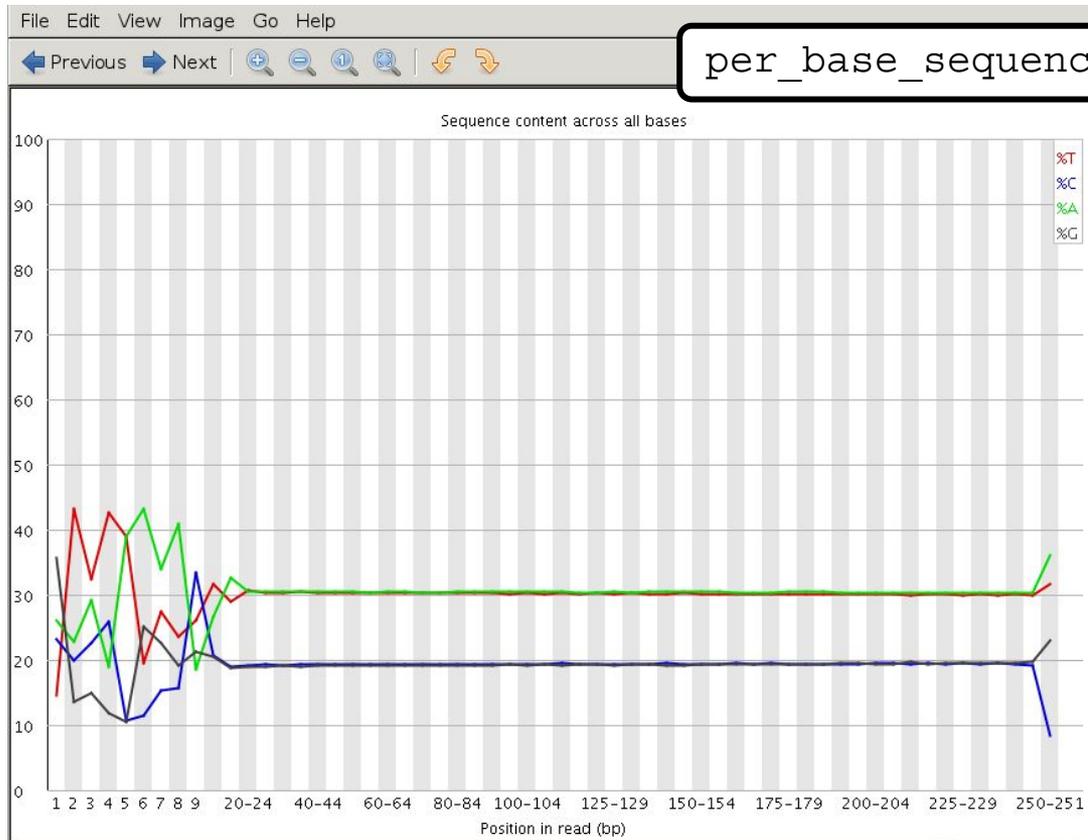
FASTQ format

```
@ERR504787.2.1 M00368:15:000000000-A0HKH:1:5:21261:10968-1 length=100
GATCGGAAGAGCACACGTCTGAACTCCAGTCACGATCAGATCTCGTATGCCGTCTTCTGCTTGAAAAA
+ERR504787.2.1 M00368:15:000000000-A0HKH:1:5:21261:10968-1 length=100
==:4AD=B8A:++A::1<:AE<C3*?F<B???<?:8:6?B*9BD;/638.=-'-.@7=) .=A:6?DDDCBB
@ERR504787.3.1 M00368:15:000000000-A0HKH:1:3:12724:25677-1 length=100
GATGTTTTGTTACTGATTGGAACCATGATTGGTGCTTTACTTGGTTTCTTCTTATTTAACCACAAGCCTG
+ERR504787.3.1 M00368:15:000000000-A0HKH:1:3:12724:25677-1 length=100
BCCFDEFHHHHJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
@ERR504787.5.1 M00368:15:000000000-A0HKH:1:2:16161:12630-1 length=100
TATTTTAAAGTGACCAAGGAATGACTCCCAATCATGGCTGTATCAACTCCAAAATTTTCTGCAACAGT
+ERR504787.5.1 M00368:15:000000000-A0HKH:1:2:16161:12630-1 length=100
CCCFHHHHJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

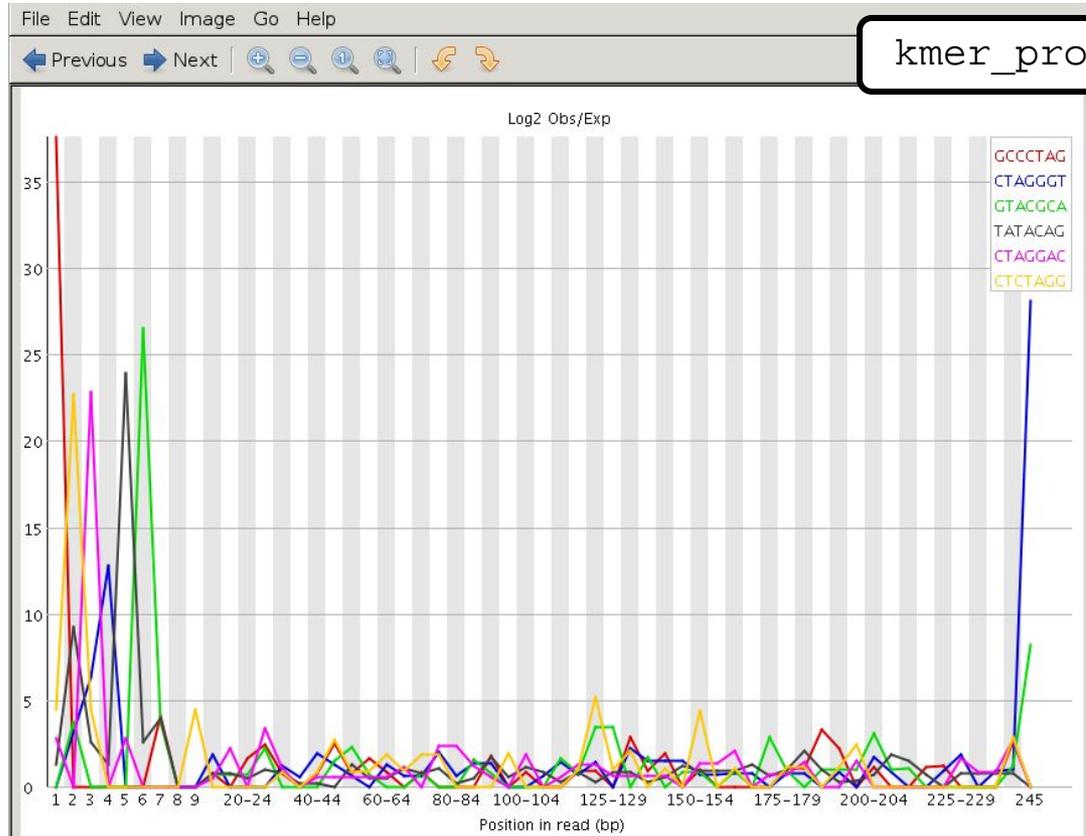
Positions are 'binned' after the first few positions



# Illumina Transposon Insertion Site



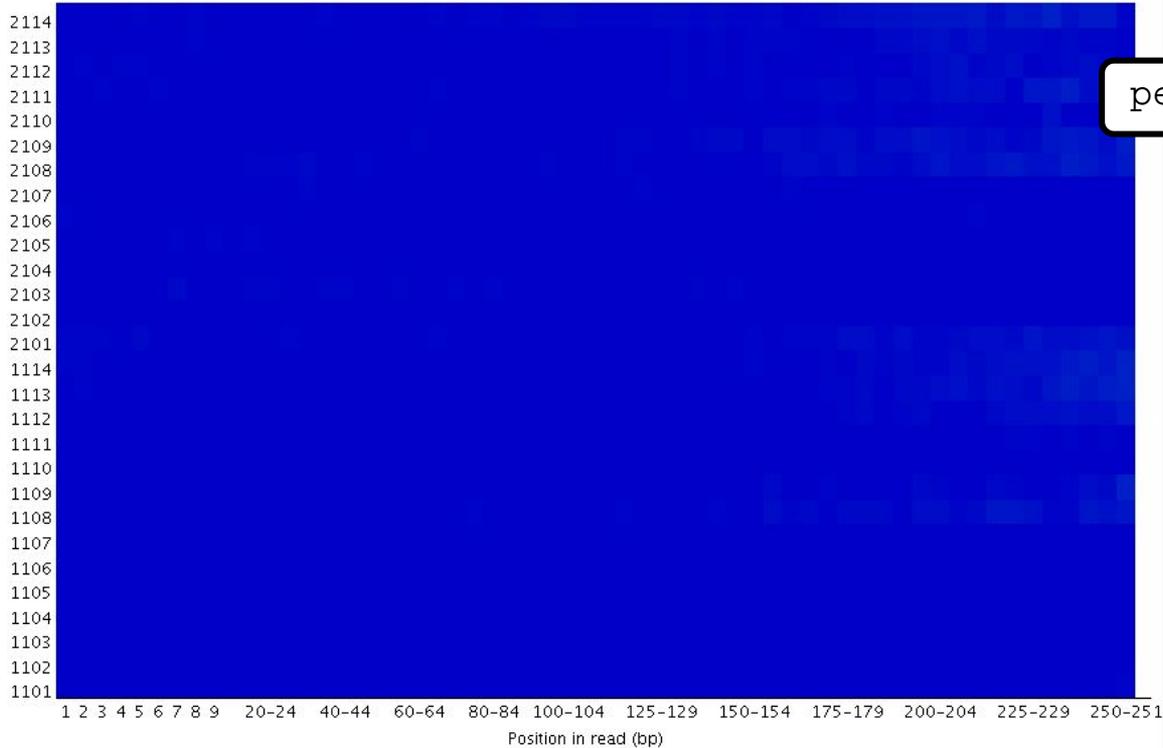
# Illumina Transposon Insertion Site



kmer\_profiles.png

# FastQC Flowcell Quality Image

Quality per tile



per\_tile\_quality.png

MiSeq  
flowcell



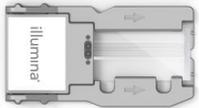
Flowcell quality mapping  
Good per\_tile quality

good quality  poor quality

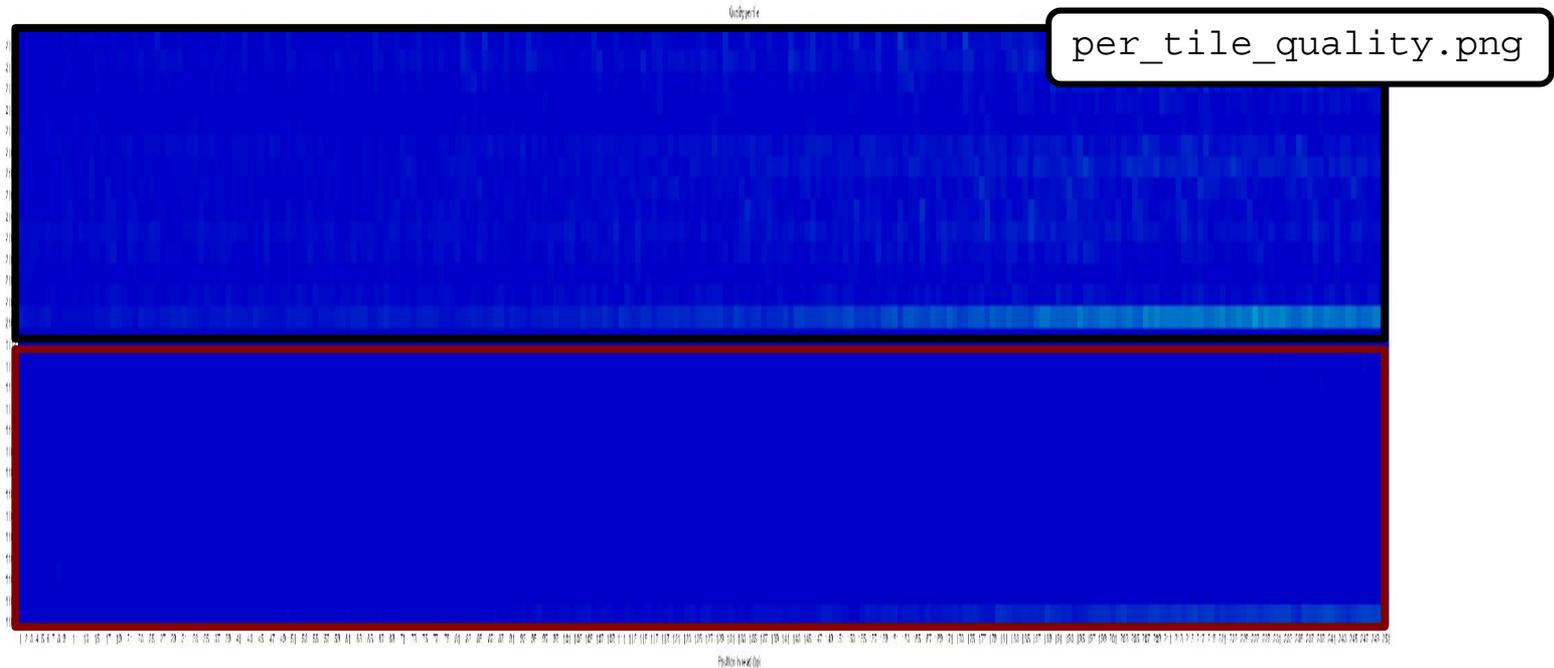
# FastQC Flowcell Quality Image

bottom of  
flowcell

MiSeq  
flowcell



top of  
flowcell



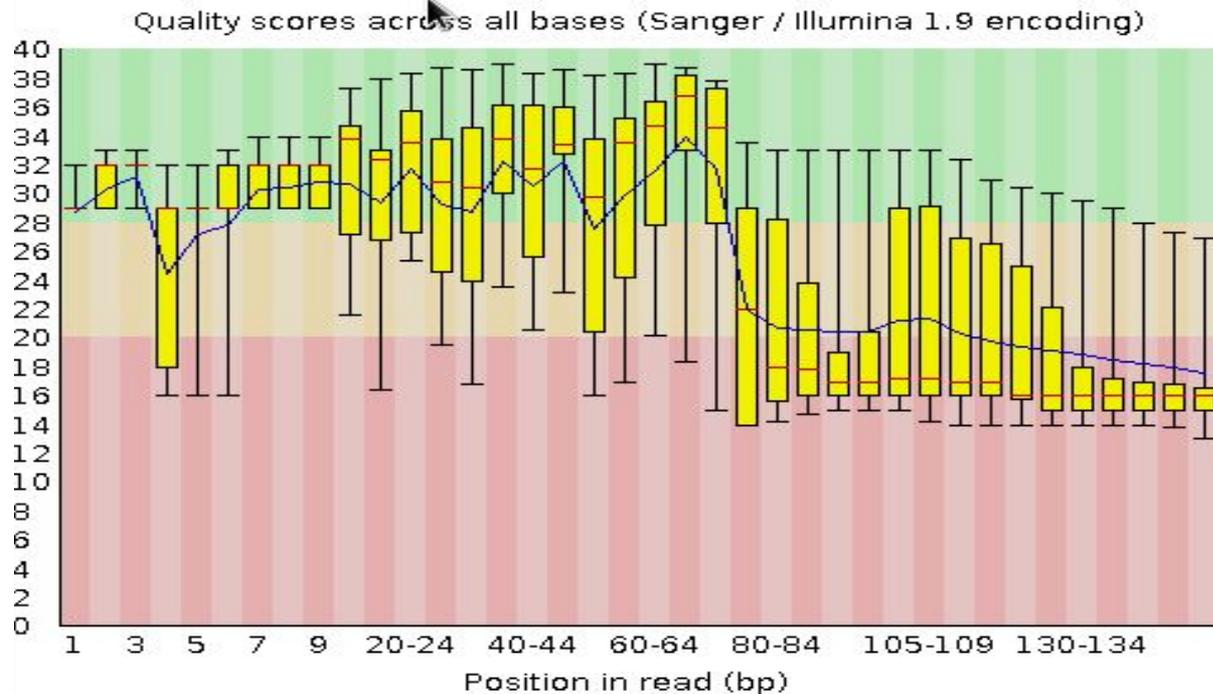
good quality  poor quality

# Failed QC Examples

# FastQC Output Image

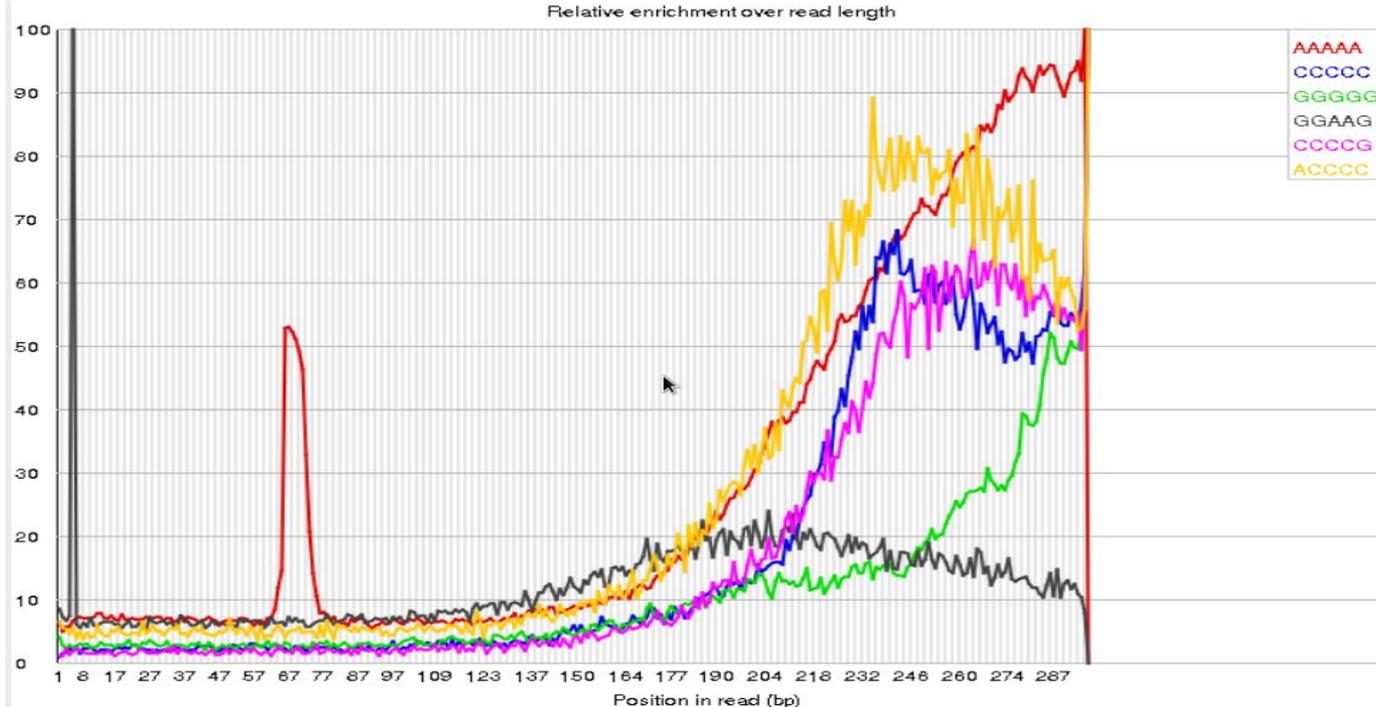
## Failed Per Base Sequence Quality

Example 1. Expired MiSeq mate-pair kit (9 months expired)



# FastQC Output Image Failed Kmer Content

Example 2. Sequence prep adapters still on ends of DNA library fragments

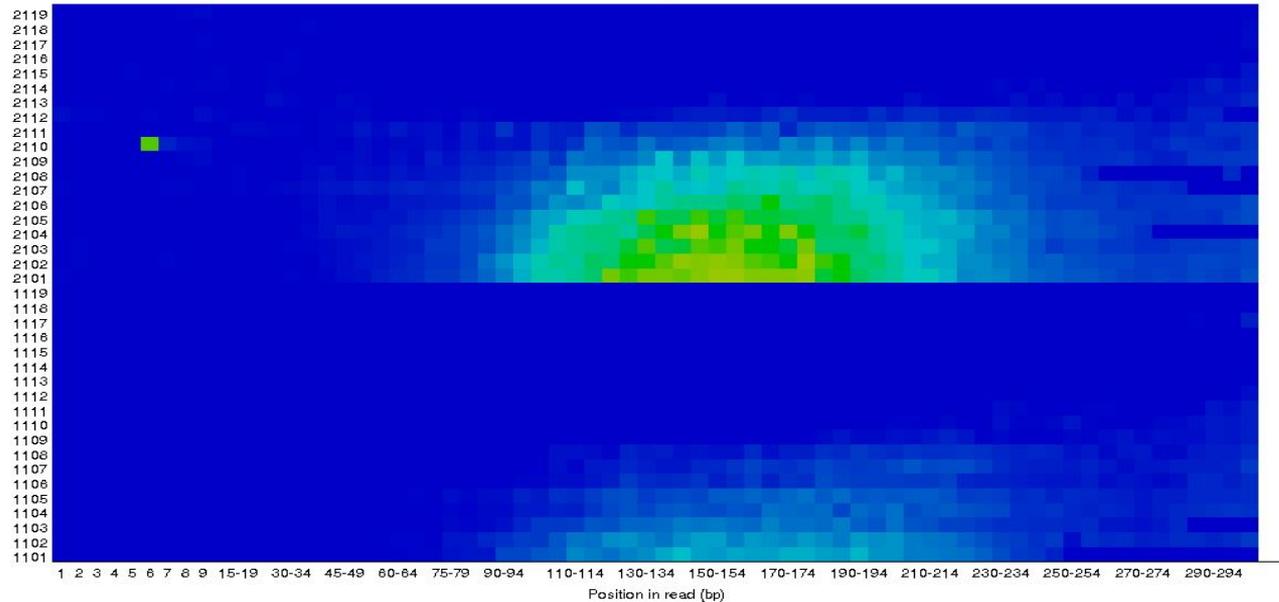
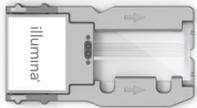


# FastQC Output Image

## Flowcell: Not Good per\_tile Quality

Example 3. Faulty flowcell

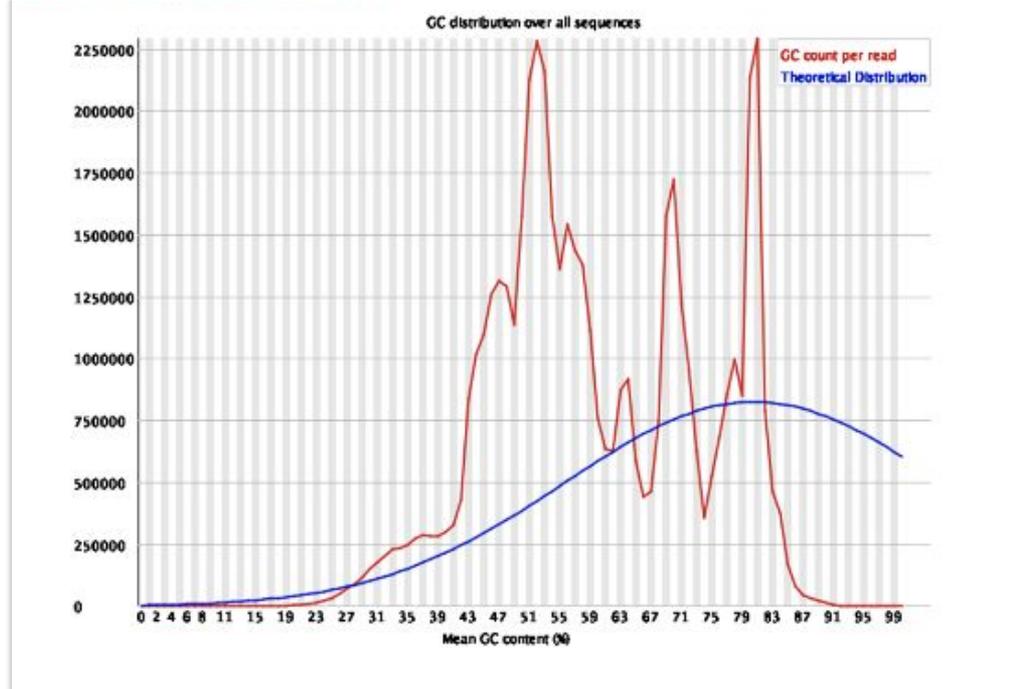
MiSeq  
flowcell



good quality  poor quality

# FastQC Output Image Failed Per Sequence GC Content

Example 4. Contamination; (multiple genomes sequenced)



# QC Quality Trimming

- Sequence quality trimming tools

```
module spider Trimmomatic
```

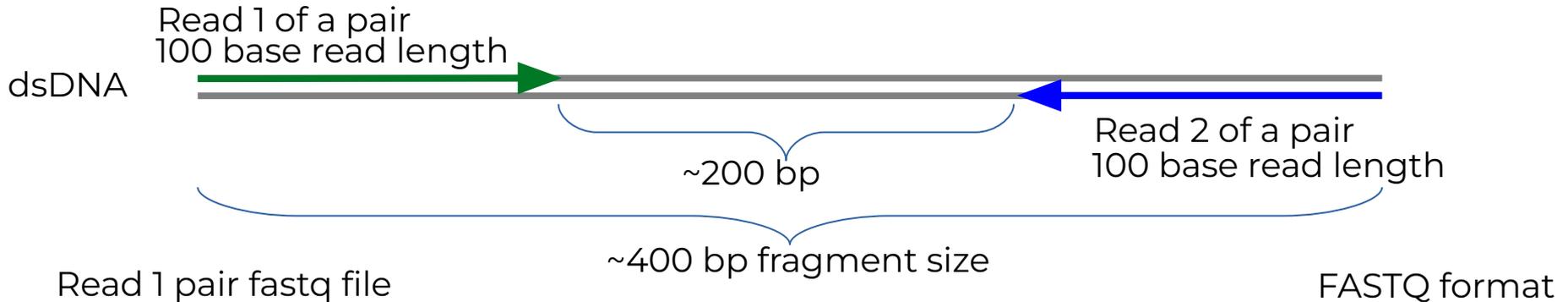
```
module spider Trim_Galore
```

- Trimmomatic will maintain paired end read pairing after trimming
- Trim reads based on quality scores
  - Trim the same number of bases from each read or
  - Use a sliding window to calculate average quality at ends of sequences
- Decide if you want to discard reads with Ns
  - some assemblers replace Ns with As or a random base G, C, A or T
- Trim adapter sequences
  - Trimmomatic has a file of Illumina adapter sequences

```
module load Trimmomatic/0.39-Java-11
```

```
ls $EBROOTTRIMMOMATIC/adapters/
```

# Paired End Short Reads



```
@M00861:1:000000000-A36BE:1:1101:14650:1529 1:N:0:8  
TTCTTAAAAATACCATAAAAGGCTTAAACTTGCCATTTACGACGGATTAATTCCAACCTTTTTCGGCTATCTTCATCTTTAAGGTAAATGACTCATAACGG  
+  
FFFHBBFFHHIIIIIIHFHHCGEFGHHIHHHIHD/?DGGHHH@DEB,5EGHGHIIHIF?FGGHHCCBFDGHFHDGHGFFFFGDFHH?DFHDFHHHFHFFHHH
```

Read 2 pair fastq file

```
@M00861:1:000000000-A36BE:1:1101:14650:1529 2:N:0:8  
ACTAAAAATCAATTTTATCAATTTCAAGCTCTACCTTATTTACTCATTATTTTAGTGATGGCCACTTTAATAAAAAATATTGGTAGCATATTTGCAATAGCGG  
+  
BFFHIIHHHFHHDGHIHHIHHHGHHHHHFFHDFHHIHI I IHIHDFHHHIHI I IH=AAFHII IHFGFHHHHHGGHHIHHFGFFFEGGHHHDGHHH/CGHIFHHH
```

dsDNA

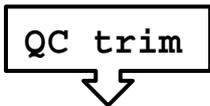


# Trimming PE Short Sequence Reads

*File 1 from sequencer*



100 bases

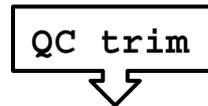


100 bases

*File 2 from sequencer*



100 bases



50 bases

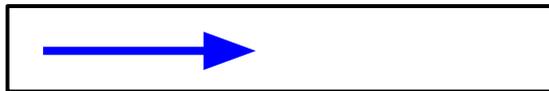
*minimun read length = 40*

*Resulting FASTQ Files with trimmed reads*

Paired end 1 trimmed file



Paired end 2 trimmed file



dsDNA

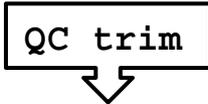


# Trimming PE Short Sequence Reads

*File 1 from sequencer*



100 bases

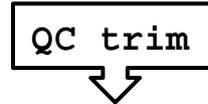


100 bases

*File 2 from sequencer*



100 bases



20 bases

*minimun read length = 40*

*Resulting FASTQ Files with trimmed reads*

Paired end 1 trimmed file



Paired end 2 trimmed file



Single end reads



# Merge Overlapping Paired End Short Reads

## fragment 1



## fragment 2



# Merge Overlapping Paired End Short Reads

## fragment 1



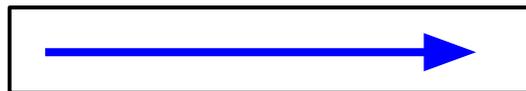
## fragment 2



Paired end read 1 (left)



Paired end read 2 (right)



# Merge Overlapping Paired End Short Reads

## fragment 1



## fragment 2



Paired end read 1 (left)



Paired end read 2 (right)



Unpaired 'merged' read



Tools for merging overlapping reads:

`module spider FLASH`

`module spider BMap`

`module spider PEAR`

# Mapping Reads to a Reference Assembly

# Mapping Short Reads to a Reference Assembly

- Align reads using bwa or bwa-mem2

```
module spider bwa
```

- Align reads using bwa-mem on GPUs

```
module spider Parabricks
```

- Align reads using bowtie or bowtie2

```
module spider Bowtie2
```

- genome index files for found here:

```
/scratch/data/bio/genome_indexes/
```

Send an email to [help@hprc.tamu.edu](mailto:help@hprc.tamu.edu) if you need an index that is not found in the genome\_indexes directory

# Visualize bam Alignment Files

# Sample bam and Reference Files

```
cd $SCRATCH/ngs_class
```

For this samtools demo, add symbolic links\* to the example files in your working directory

```
ln -s /scratch/data/bio/training/alignments/dr34.sam
```

Add a symbolic link to the example reference genome fasta file

```
ln -s /scratch/data/bio/training/genomes/c_dublinsiensis.fa
```

Use the tab key when typing these long paths

\* The symbolic links are used to make the commands shorter for demonstration purposes only. You do not need to make symbolic links in order to use **samtools** **tvview**

# Sorting Alignment sam/bam Files

- Sequence Alignment/Map format (sam)
  - view sam files using the UNIX command: `more dr34.sam`
- Binary Alignment/Map format (bam)
  - Compressed (binary) sam files need samtools to view
    - `module load GCC/10.2.0 SAMtools/1.11`
  - Recommended: sort sam/bam file based on coordinate into bam format
  - `samtools sort -@ 1 -m 2G -o dr34.bam dr34.sam`
  - Create an index of the bam file using samtools
    - A samtools index is needed prior to viewing bam files in browsers

```
samtools index dr34.bam
```

```
dr34.bam.bai
```

# Viewing sam/bam Files

Viewing bam files using samtools

```
samtools view dr34.bam | more
```

view only alignments

```
samtools view -H dr34.bam
```

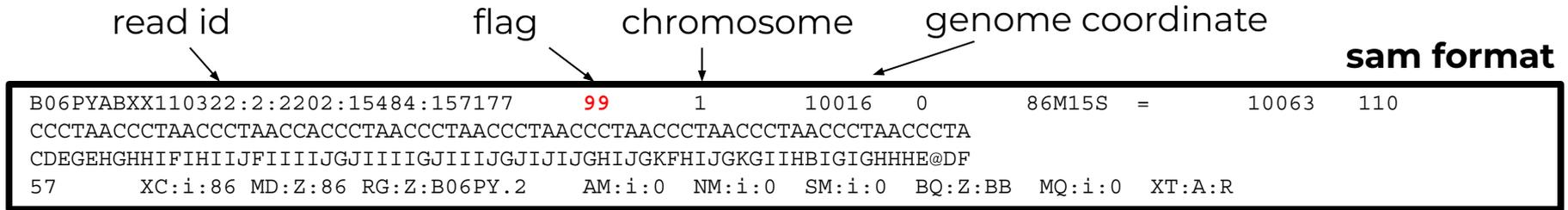
view only header

```
samtools view -h dr34.bam | more
```

view header + alignments

# Sam Flags and Bits

- Flags describe alignments (the flag value is the sum of bits)



bits: 1 2 4 8 16 32 64 128 256 512 1024 2048

$$1 + 2 + 32 + 64 = 99$$

- Filter bam alignments based on bit in flag (-f and/or -F)
  - Keep only reads that are 'mapped in proper pair'

```
samtools view -h -b -f 2 dr34.bam > dr34_paired_reads.bam
```

- Keep all except reads that are 'PCR or optical duplicate'

```
samtools view -h -b -F 1024 dr34.bam > dr34_dedup_reads.bam
```

# Sam Flags and Bits

<https://broadinstitute.github.io/picard/explain-flags.html>

### Decoding SAM flags

This utility makes it easy to identify what are the properties of a read based on its SAM flag value, or conversely, to find what the SAM Flag value would be for a given combination of properties.

To decode a given SAM flag value, just enter the number in the field below. The encoded properties will be listed under Summary below, to the right.

SAM Flag:

Toggle first in pair/ second in pair

#### Find SAM flag by property:

To find out what the SAM flag value would be for a given combination of properties, tick the boxes for those that you'd like to include. The flag value will be shown in the SAM Flag field above.

Bits	<input checked="" type="checkbox"/>	read paired
2	<input checked="" type="checkbox"/>	read mapped in proper pair
4	<input type="checkbox"/>	read unmapped
8	<input type="checkbox"/>	mate unmapped
16	<input type="checkbox"/>	read reverse strand
32	<input checked="" type="checkbox"/>	mate reverse strand
64	<input checked="" type="checkbox"/>	first in pair
128	<input type="checkbox"/>	second in pair
256	<input type="checkbox"/>	not primary alignment
512	<input type="checkbox"/>	read fails platform/vendor quality checks
1024	<input type="checkbox"/>	read is PCR or optical duplicate
2048	<input type="checkbox"/>	supplementary alignment

#### Summary:

- read paired
- read mapped in proper pair
- mate reverse strand
- first in pair

**SAM Flag is the sum of Bits**

$$99 = 64 + 32 + 2 + 1$$

# Alignment Statistics

```
samtools flagstat dr34.bam
```

```
150000 + 0 in total (QC-passed reads + QC-failed reads)
0 + 0 secondary
0 + 0 supplementary
0 + 0 duplicates
140150 + 0 mapped (93.43% : N/A)
150000 + 0 paired in sequencing
75002 + 0 read1
74998 + 0 read2
85639 + 0 properly paired (57.09% : N/A)
136854 + 0 with itself and mate mapped
3296 + 0 singletons (2.20% : N/A)
909 + 0 with mate mapped to a different chr
56 + 0 with mate mapped to a different chr (mapQ>=5)
```

Both reads in the pair are mapped  
on the same chromosome  
and in FR or RF orientation





# SAMtools with a Reference Genome

Reference genome sequence displayed on top when reference file is provided

```
samtools tview dr34.bam c_dublinsiensis.fa
```



```
1      11      21      31      41      51      61      71      81      91      101     111     121     131
GATCAAGTTGAGAGACAAATAGAGTTGTTTATTTAATTCAGAGAAGAATCAGTTGTTTATTGTTAAGATCACAGACAGAATTCTGTTGTTTGTAGTCGCAAAGAATCAGCTACAATACAGTTAGAGATACAGTATA
```





# Sequence Variant Calling

# Sequence Variant Calling

- Start with aligning reads to a reference
  - Parabricks aligns using bwa-mem and calls variants using GATK on GPUs
  - GATK does not require QC trimming
  - Mark PCR duplicates with Picard
- Differentiate between sequencing errors and SNPs
  - Calling SNPs may require a min read depth of 10x (higher for indels)
  - Calling variants may require 1/3 of reads to contain SNP
  - Strand bias may result as a consequence of the sequencing chemistry's response to certain DNA sequence motifs but it can be detected computationally
- BLAST reads with SNPs to identify variant calls due to misalignments especially with duplicated genes

• Variant Call Format (vcf) – standard format of variant calls

• Identify multiple-nucleotide polymorphism (MNP)

- Two SNPs within a single codon

	codon	translation
Reference:	<b>TTT</b>	Phe
SNP 1:	<b>TTA</b>	Leu
SNP 2:	<b>TAT</b>	Tyr
SNP 1 + 2:	<b>TAA</b>	<b>STOP</b>

# Marking PCR Duplicates

- PCR duplicates are artifacts resulting from a PCR amplification step during NGS library preparations.
- PCR duplicates should be removed/marked as to not bias the frequency of variants or gene expression levels
  - Use picard tools to mark duplicates
  - freebayes will ignore marked duplicates during variant calling

```
module spider picard
```

# Variant Calling Tools

1. Parabricks
  - a. processing alignments and variant calling on GPUs
2. GATK
  - a. No need to QC trim reads—the GATK best practices pipeline will perform the necessary steps, including marking PCR duplicates
  - b. You need a set of known variants for your species (dbSNP), or you can bootstrap your population to get variant frequency
  - c. Used in conjunction with other tools such as samtools and picard
3. SAMtools and BCFtools
4. freebayes
5. VarScan

# Sample vcf File Format

```
##fileformat=VCFv4.0
##fileDate=20110705
##reference=1000GenomesPilot-NCBI37
##phasing=partial
##INFO=<ID=NS,Number=1,Type=Integer,Description="Number of Samples With Data">
##INFO=<ID=DP,Number=1,Type=Integer,Description="Total Depth">
##INFO=<ID=AF,Number=.,Type=Float,Description="Allele Frequency">
##INFO=<ID=AA,Number=1,Type=String,Description="Ancestral Allele">
##INFO=<ID=DB,Number=0,Type=Flag,Description="dbSNP membership, build 129">
##INFO=<ID=H2,Number=0,Type=Flag,Description="HapMap2 membership">
##FILTER=<ID=q10,Description="Quality below 10">
##FILTER=<ID=s50,Description="Less than 50% of samples have data">
##FORMAT=<ID=GQ,Number=1,Type=Integer,Description="Genotype Quality">
##FORMAT=<ID=GT,Number=1,Type=String,Description="Genotype">
##FORMAT=<ID=DP,Number=1,Type=Integer,Description="Read Depth">
##FORMAT=<ID=HQ,Number=2,Type=Integer,Description="Haplotype Quality">
#CHROM POS ID REF ALT QUAL FILTER INFO FORMAT Sample1 Sample2
2 4370 rs6057 G A 29 . NS=2;DP=13;AF=0.5;DB;H2 GT:GQ:DP:HQ 0|0:48:1:52,51 1|0:48:8:51,51
2 7330 . T A 3 q10 NS=5;DP=12;AF=0.017 GT:GQ:DP:HQ 0|0:46:3:58,50 0|1:3:5:65,3
2 110696 rs6055 A G,T 67 PASS NS=2;DP=10;AF=0.333,0.667;AA=T;DB GT:GQ:DP:HQ 1|2:21:6:23,27 2|1:2:0:18,2
2 130237 . T . 47 . NS=2;DP=16;AA=T GT:GQ:DP:HQ 0|0:54:7:56,60 0|0:48:4:56,51
2 134567 microsat1 GTCT G,GTACT 50 PASS NS=2;DP=9;AA=G GT:GQ:DP 0/1:35:4 0/2:17:2
```

3 more columns not shown due to width of rows

# vcf File Column Descriptions

```
##fileformat=VCFv4.0
##fileDate=20110705
##reference=1000GenomesPilot-NCBI37
##phasing=partial
##INFO=<ID=NS,Number=1,Type=Integer,Description="Number of Samples With Data">
##INFO=<ID=DP,Number=1,Type=Integer,Description="Total Depth">
##INFO=<ID=AF,Number=.,Type=Float,Description="Allele Frequency">
##INFO=<ID=AA,Number=1,Type=String,Description="Ancestral Allele">
##INFO=<ID=DB,Number=0,Type=Flag,Description="dbSNP membership, build 129">
##INFO=<ID=H2,Number=0,Type=Flag,Description="HapMap2 membership">
##FILTER=<ID=q10,Description="Quality below 10">
##FILTER=<ID=s50,Description="Less than 50% of samples have data">
##FORMAT=<ID=GQ,Number=1,Type=Integer,Description="Genotype Quality">
##FORMAT=<ID=GT,Number=1,Type=String,Description="Genotype">
##FORMAT=<ID=DP,Number=1,Type=Integer,Description="Read Depth">
##FORMAT=<ID=HQ,Number=2,Type=Integer,Description="Haplotype Quality">
#CHROM POS ID REF ALT QUAL FILTER INFO
2 4370 rs6057 G A 29 . NS=2;DP=13;AF=0.5;DB;H2
2 7330 . T A 3 q10 NS=5;DP=12;AF=0.017
2 110696 rs6055 A G,T 67 PASS NS=2;DP=10;AF=0.333,0.667;AA=T;DB
2 130237 . T . 47 . NS=2;DP=16;AA=T
2 134567 microsat1 GTCT G,GTACT 50 PASS NS=2;DP=9;AA=G
```

variants that are phased are inherited together (paternal)

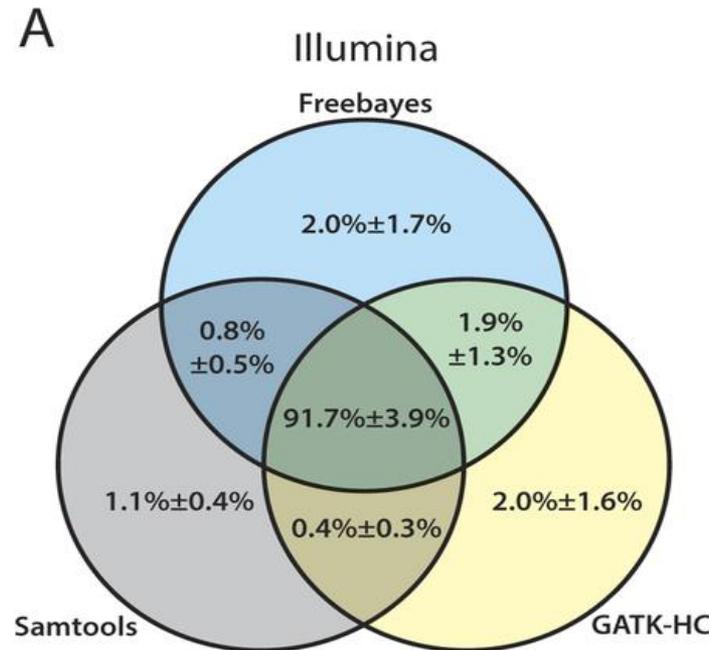
| indicates phased variants  
/ indicates non-phased variants

FORMAT	Sample1	Sample2
GT:GQ:DP:HQ	0 0:48:1:52,51	1 0:48:8:51,51
GT:GQ:DP:HQ	0 0:46:3:58,50	0 1:3:5:65,3
GT:GQ:DP:HQ	1 2:21:6:23,27	2 1:2:0:18,2
GT:GQ:DP:HQ	0 0:54:7:56,60	0 0:48:4:56,51
GT:GQ:DP	0/1:35:4	0/2:17:2

INFO section is for all samples combined

Sample1 haplotypes: **GTGT** and **GTTT**  
Sample2 haplotypes: **ATTT** and **GAGT**

# Summarizing Variant Calls from Different Tools



The mean percentage with standard deviation of confidence variant calls with equal to or higher than the quality score threshold of 20 are represented for (A) Illumina data sets

Huang et al 2015 doi:10.1038/srep17875

# Consequence of Amino Acid Change

- Assess consequence of amino acid change based on sequence conservation across multiple species using the PROVEAN tool
- Variants with a score equal to or below -2.5 are considered “deleterious”

**module spider PROVEAN**

```
## PROVEAN v1.1 output ##
# Query sequence file:  CTRG_00013.fa
# Variation file:      CTRG_00013.var
# Protein database:   /scratch/datasets/blast/nr
[16:01:13] searching related sequences...
[16:16:36] clustering subject sequences...
# Number of clusters:    30
# Number of supporting sequences used: 245
[16:18:39] computing delta alignment scores...
## PROVEAN scores ##
# VARIATION SCORE
A431S   -0.455
E411K   -3.051
E226Q   -1.564
```

Verify that enough supporting sequences were found

**“deleterious”**

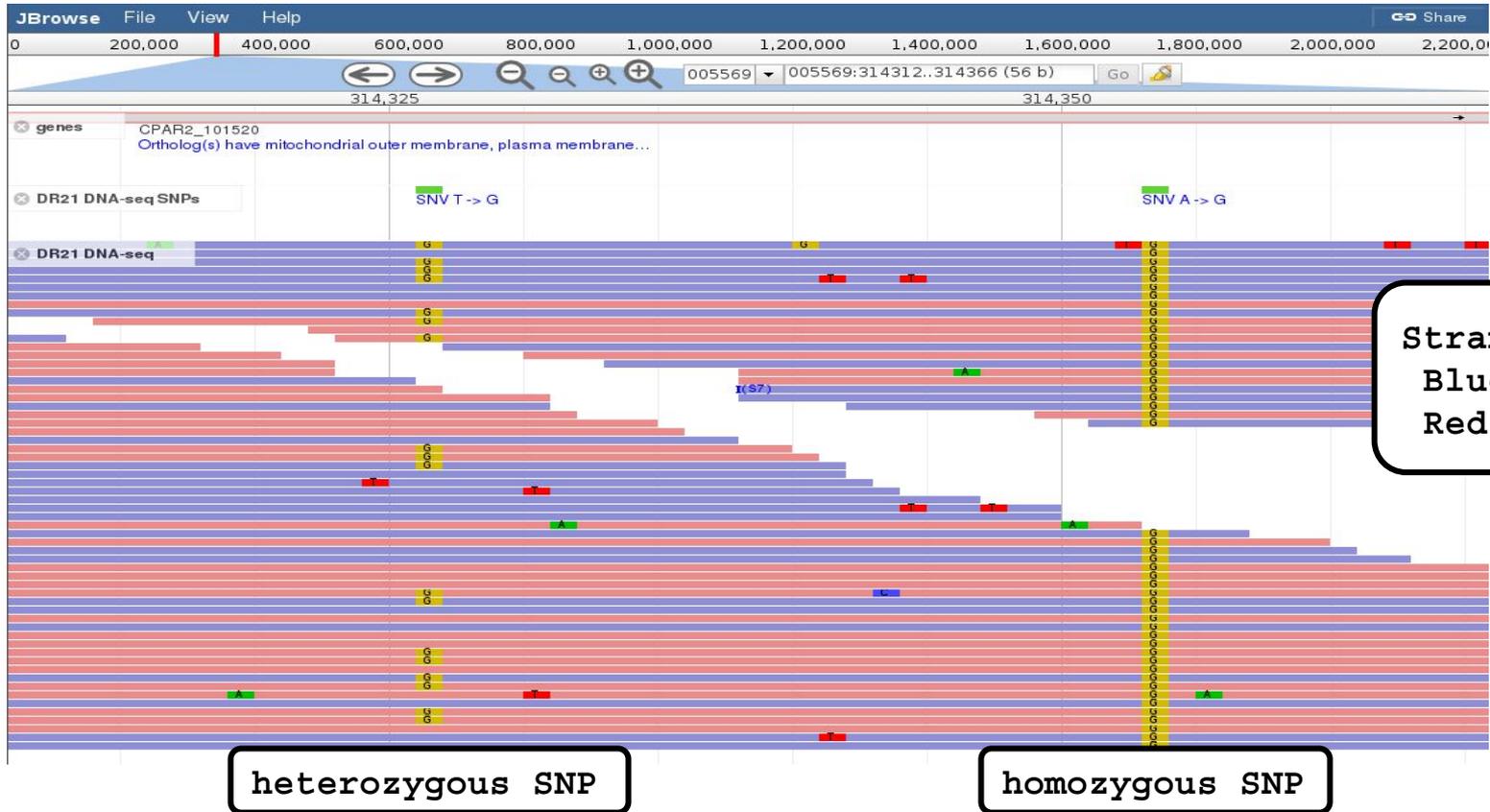
# Annotate Variants

module spider snpEff

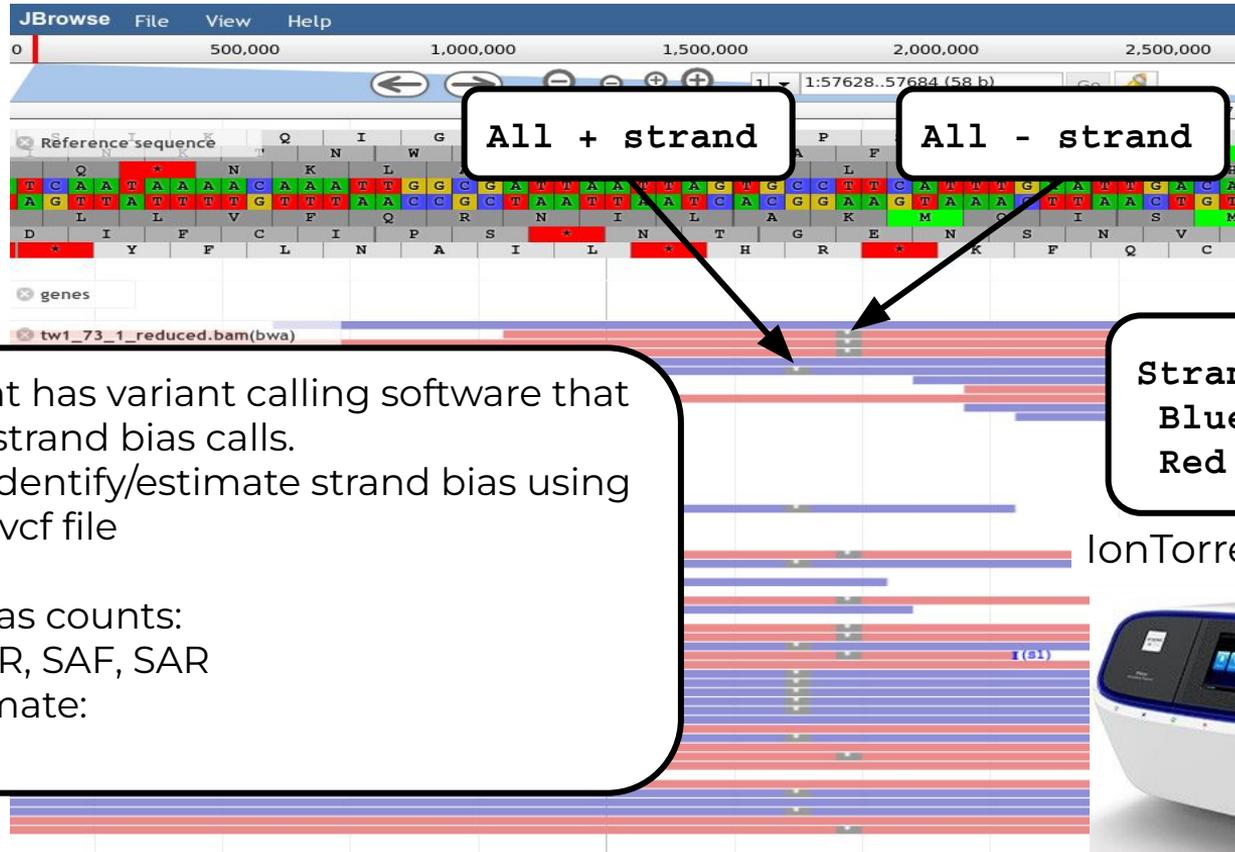
- A file of variant calls in vcf format is needed
- A reference sequence with gene annotations is needed
- snpEff annotates a vcf file
  - There are > 2,500 pre-built databases available and you can build your own if needed
  - Annotates MNP (multiple nucleotide polymorphism)
    - Codon change due to two SNPs: ACA → GGA

```
5          325795      .          AC          GG          23.8901      .
AB=0.428571;ABP=3.32051;AC=1;AF=0.5;AN=2;AO=3;CIGAR=2X;DP=7;DPB=7;DPRA=0;EPP=3.73412;
EPPR=3.0103;GTI=0;LEN=2;MEANALT=1;MQM=33;MQMR=48.5;NS=1;NUMALT=1;ODDS=5.49681;PAIRED=0;
PAIREDR=0.5;PAO=0;PQA=0;PQR=0;PRO=0;QA=114;QR=150;RO=4;RPL=3;RPP=9.52472;RPPR=3.0103;
RPR=0;RUN=1;SAF=2;SAP=3.73412;SAR=1;SRF=2;SRP=3.0103;SRR=2;TYPE=mnnp;technology.ILLUMINA=1;
ANN=GG|missense_variant|MODERATE|CD36_51230|CD36_51230|transcript|CAX41505.1|
protein_coding|1/1|c.1657_1658delACinsGG|p.Thr553Gly|1657/1851|1657/1851|553/616||
GT:DP:RO:QR:AO:QA:GL          0/1:7:4:150:3:114:-6.7054,0,-11.1847
```

# Viewing SNPs in a Diploid Organism



# Example of Sequencing Strand Bias



IonTorrent has variant calling software that can skip strand bias calls. You can identify/estimate strand bias using values in vcf file

Strand bias counts:  
SRF, SRR, SAF, SAR  
Bias estimate:  
SAP

**Strand:**  
Blue = +  
Red = -

IonTorrent Proton



# RNA-seq Overview

# RNA-seq Applications

- Differential Expression (DE) and transcript abundance
  - HISAT2, STAR, Cufflinks, Cuffmerge, Cuffdiff
  - DESeq and DESeq2 (R package)
  - EdgeR (R package)
- Transcriptome assembly (find isoforms and rare transcripts)
  - *de novo* (Trinity, SOAPdenovo-Trans)
  - reference based (Trinity, StringTie)
- Genome Annotation
  - Align to assembly for validation of gene models
- Variant Calling
  - STAR/Picard/GATK (Haplotype Caller (HC) in RNA-seq mode)
- *de novo* genome assembly scaffolding
  - L\_RNA\_scaffolder
- Identify fusion transcripts
  - tophat-fusion

# Sequence Depth for RNA-seq Differential Expression

## **RNA-seq differential expression studies: more sequence or more replication?**

Liu, Yuwen, Zhou, Jie and White, Kevin P. [Bioinformatics](#). 2014 Feb 1; 30(3): 301–304.

doi: [10.1093/bioinformatics/btt688](https://doi.org/10.1093/bioinformatics/btt688) PMID: PMC3904521

- Using more biological replicates instead of increasing sequencing depth resulted in improved accuracy of expression estimation
- Use more biological replicates at lower sequencing depth is more beneficial than fewer samples at a higher sequencing depth
- Increasing sequence depth is beneficial for exon or transcript-specific expression studies

# RNA-seq Transcriptome Assembly

- Assembly with a reference genome

```
module spider Trinity
```

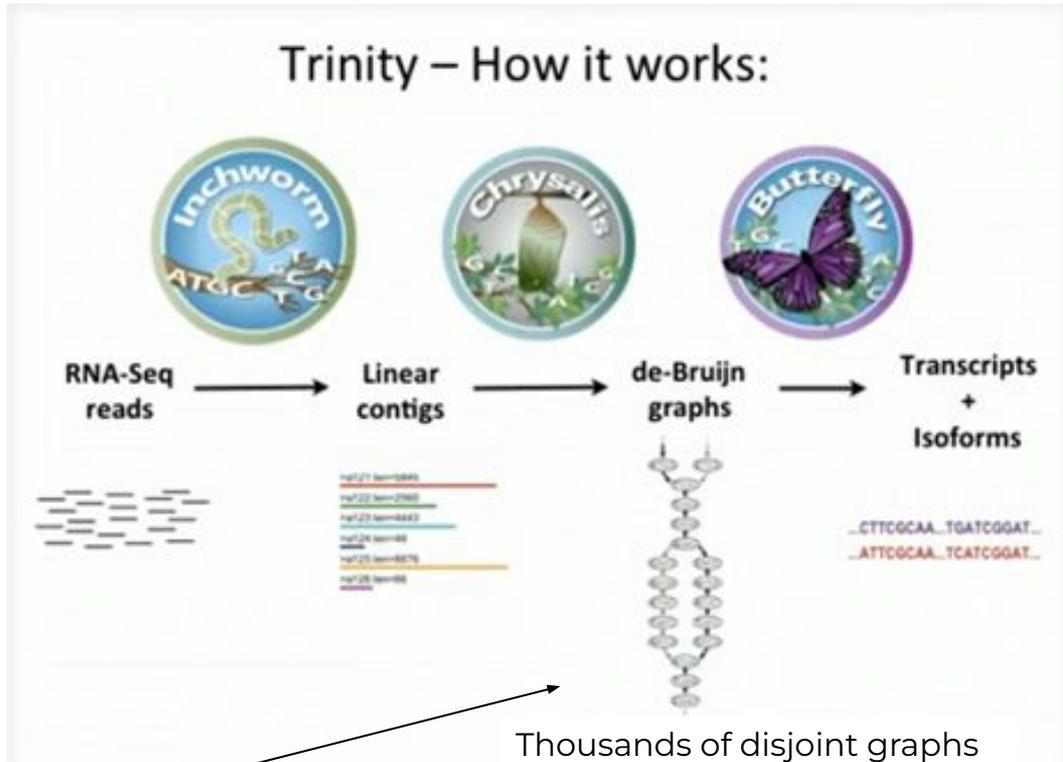
```
module spider HISAT2 Cufflinks
```

```
module spider StringTie
```

- *de novo* assembly without a reference genome

```
module spider Trinity
```

# Trinity – How it works:



Thousands of disjoint graphs

ideally one graph per gene/transcript

Broad Institute

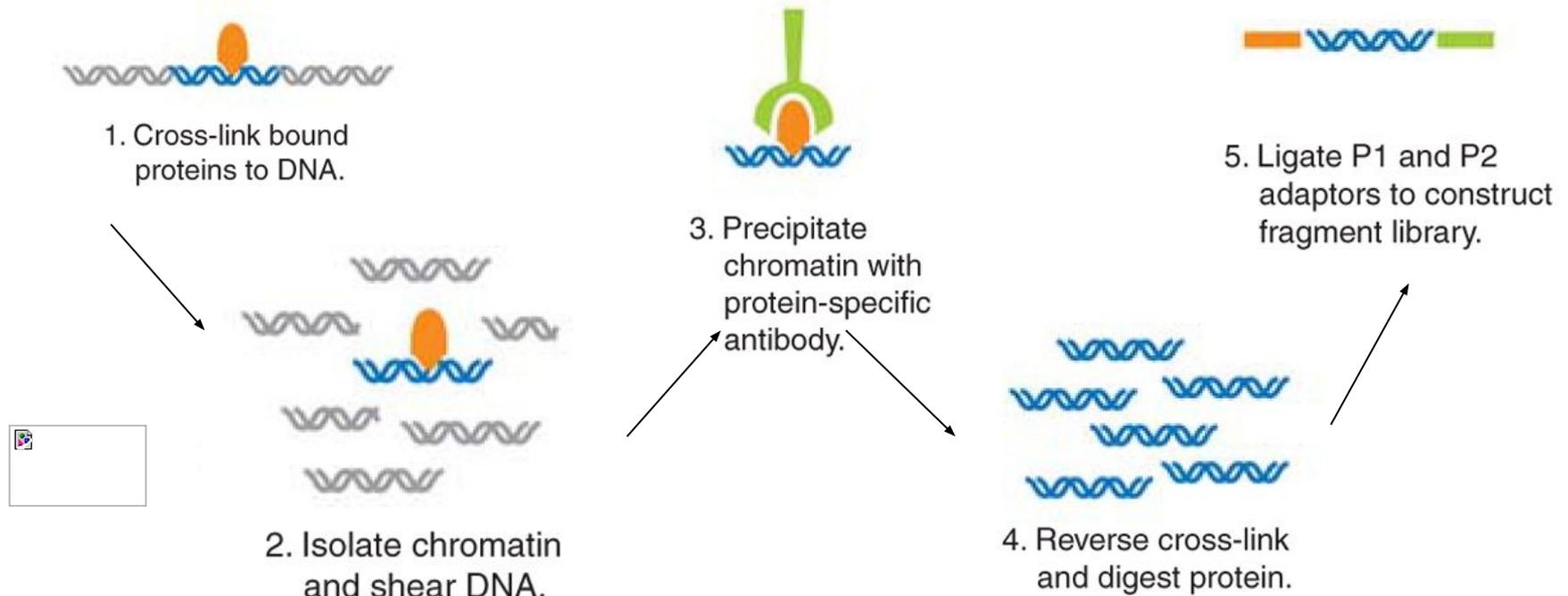
<https://www.broadinstitute.org/videos/introduction-de-novo-rna-seq-assembly-using-trinity>

# Running Trinity on Grace

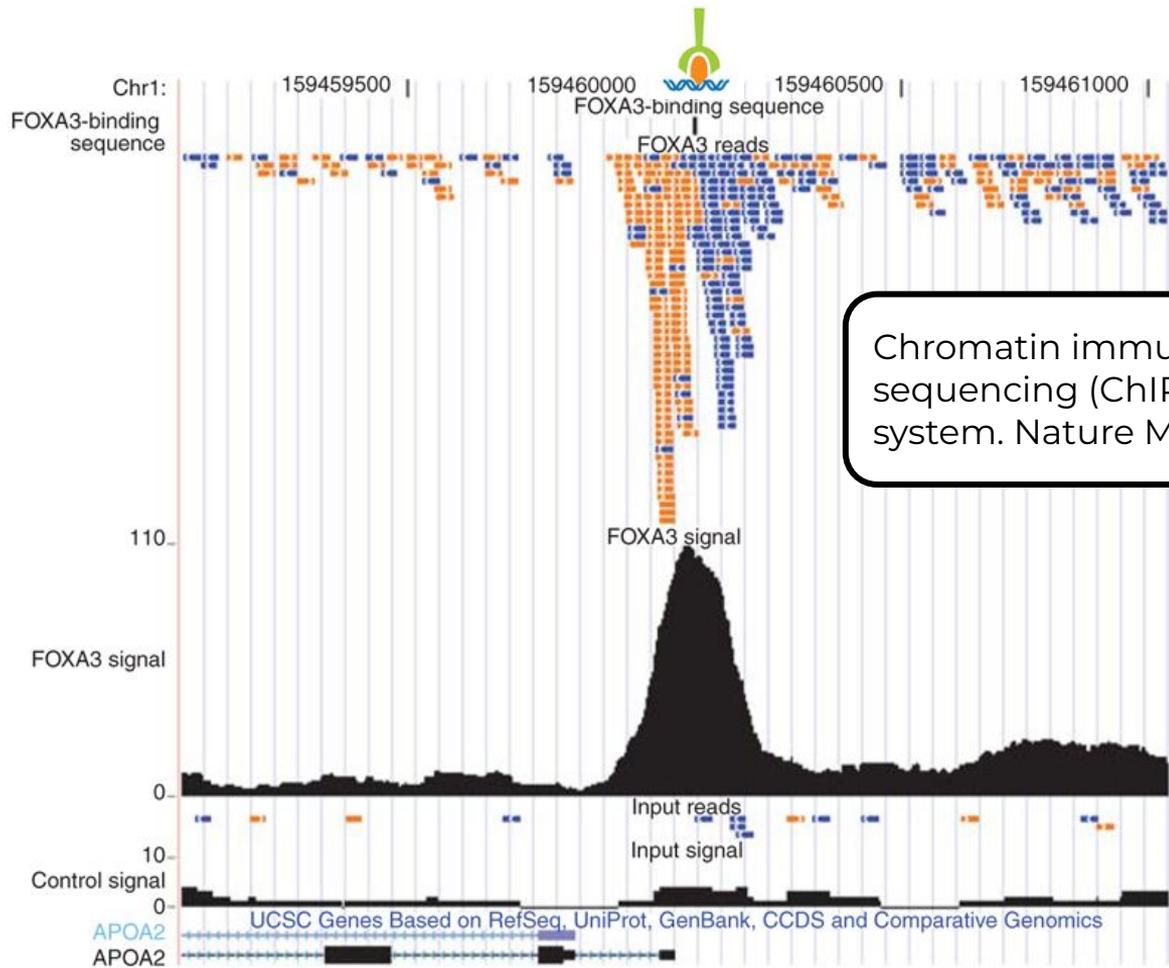
- Trinity creates 100,000s of intermediate files
  - Contact [help@hprc.tamu.edu](mailto:help@hprc.tamu.edu) and request a file quota increase before running Trinity or use the **\$TMPDIR** in your job script
  - Run one Trinity job at a time and check resource usage
    - `showquota`
    - It is recommended not to run multiple Trinity jobs unless you are using **\$TMPDIR**
  - Trinity creates checkpoints and can be restarted if it stops due to file/disk quota met, out of memory or runtime
    - Checkpoints are not available when running Trinity in Galaxy
    - Checkpoints are not available if you use **\$TMPDIR** with Trinity
      - need to rsync results from **\$TMPDIR** at end of job script
      - checkpoints are stored in **\$TMPDIR** which is deleted after the job ends
- See [GCATemplates](#) for sample Trinity scripts

# ChIP-seq

Chromatin immunoprecipitation (ChIP) is a technique for identifying and characterizing elements in protein-DNA interactions involved in gene regulation or chromatin organization.

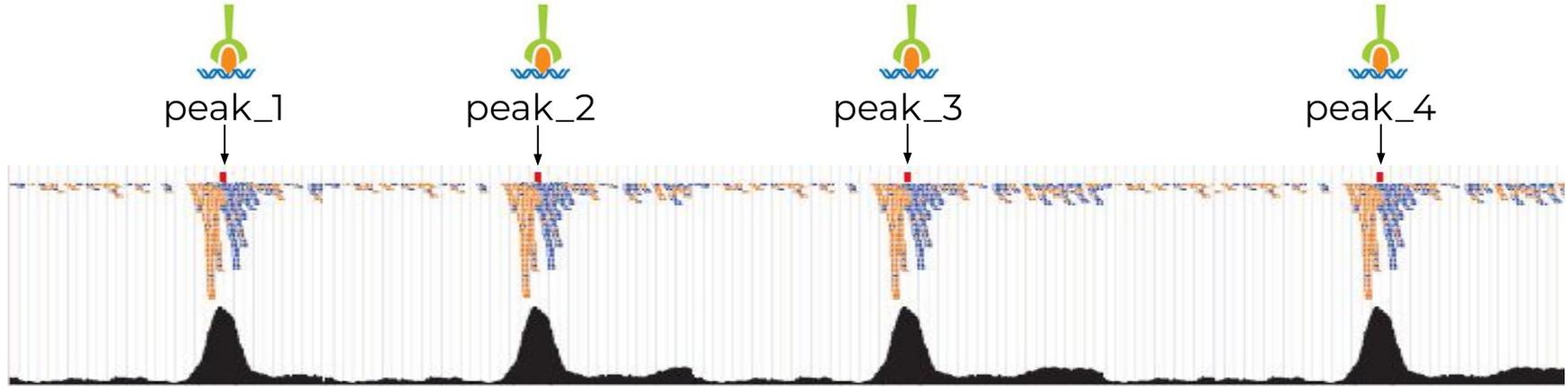


Chromatin immunoprecipitation sequencing (ChIP-Seq) on the SOLiD™ system. Nature Methods 6, (2009)



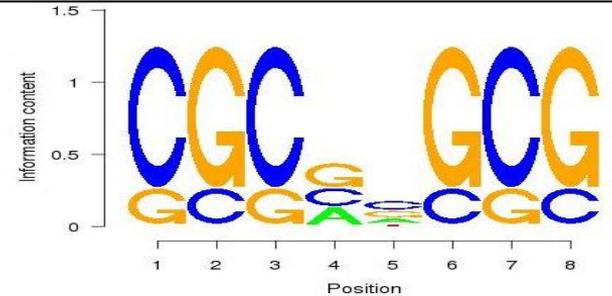
Chromatin immunoprecipitation sequencing (ChIP-Seq) on the SOLiD™ system. Nature Methods 6, (2009)

The goal is to find a consensus DNA sequence among the sequences at each peak which will give us the DNA sequence motif that a protein recognizes and binds



A sequence logo can be used to represent the DNA sequence motif where the protein binds

Generate a sequence logo with the R package seqLogo

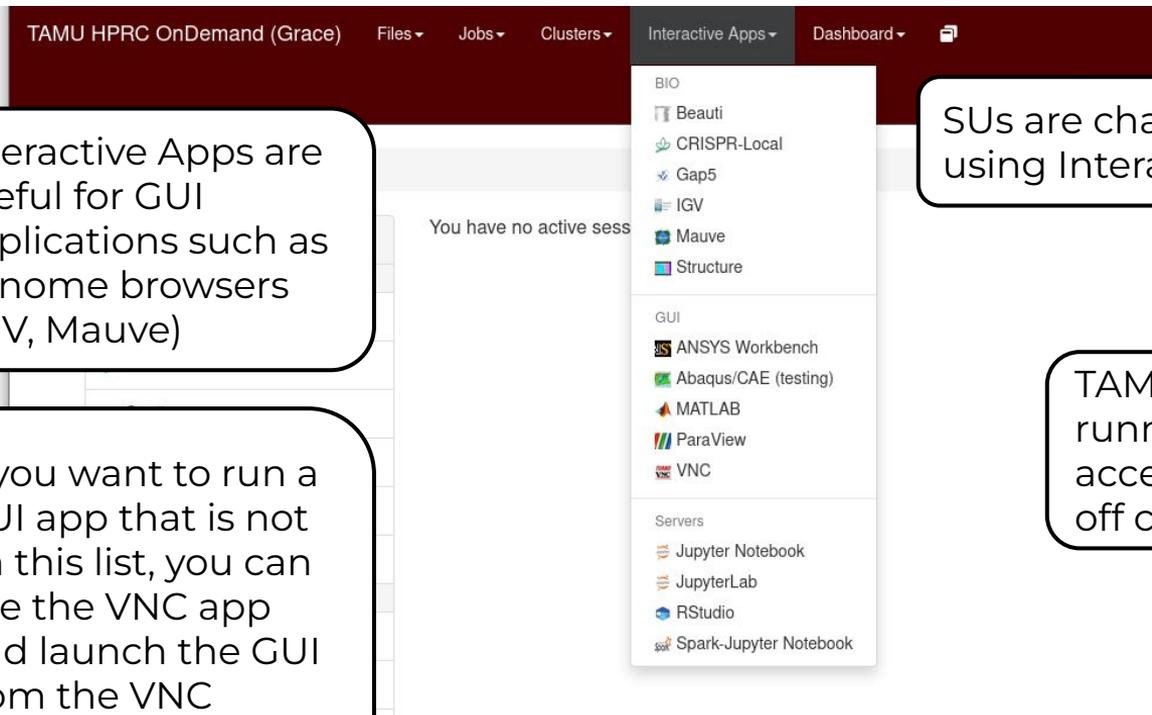


```
module load iccifort/2020.4.304 impi/2019.9.304 R tamu/4.1.0
```

# ChIP-seq Tools

- Protein-DNA interactions
  - `module spider MACS2`
- Background signal differentiation
  - `module spider deepTools`
- Identify enriched domains from histone modification ChIP-seq data
  - `module spider SICER2`

# HPRC Portal Interactive Apps



Interactive Apps are useful for GUI applications such as genome browsers (IGV, Mauve)

If you want to run a GUI app that is not on this list, you can use the VNC app and launch the GUI from the VNC terminal

SUs are charged for using Interactive Apps

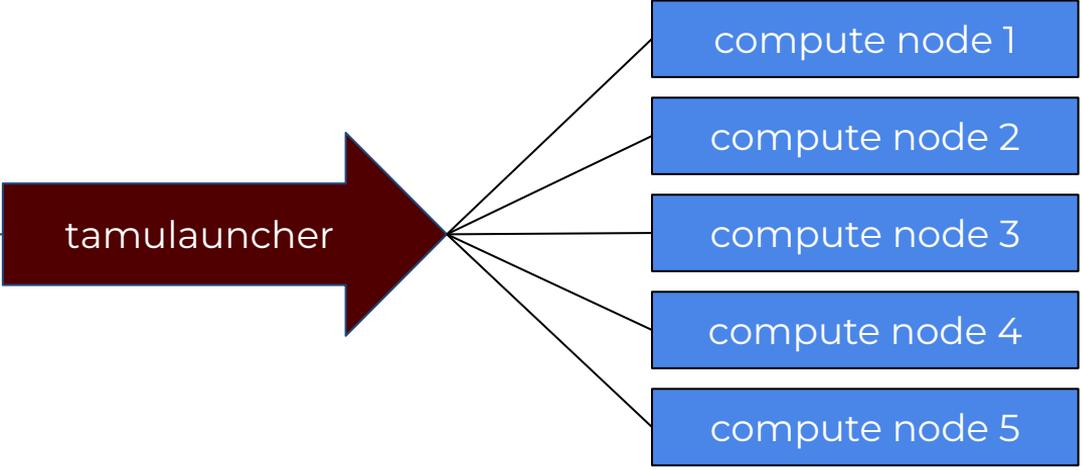
TAMU [VPN](#) must be running in order to access the portal from off campus

[portal-grace.hprc.tamu.edu](https://portal-grace.hprc.tamu.edu)

# TAMU Launcher

```
blastn -query chunk0000.fa -db 'nt.bacteria' -task megablast -out chunk0000.fa.out -outfmt 6
blastn -query chunk0001.fa -db 'nt.bacteria' -task megablast -out chunk0001.fa.out -outfmt 6
blastn -query chunk0002.fa -db 'nt.bacteria' -task megablast -out chunk0002.fa.out -outfmt 6
blastn -query chunk0003.fa -db 'nt.bacteria' -task megablast -out chunk0003.fa.out -outfmt 6
blastn -query chunk0004.fa -db 'nt.bacteria' -task megablast -out chunk0004.fa.out -outfmt 6
blastn -query chunk0005.fa -db 'nt.bacteria' -task megablast -out chunk0005.fa.out -outfmt 6
blastn -query chunk0006.fa -db 'nt.bacteria' -task megablast -out chunk0006.fa.out -outfmt 6
blastn -query chunk0007.fa -db 'nt.bacteria' -task megablast -out chunk0007.fa.out -outfmt 6
blastn -query chunk0008.fa -db 'nt.bacteria' -task megablast -out chunk0008.fa.out -outfmt 6
blastn -query chunk0009.fa -db 'nt.bacteria' -task megablast -out chunk0009.fa.out -outfmt 6
blastn -query chunk0010.fa -db 'nt.bacteria' -task megablast -out chunk0010.fa.out -outfmt 6
blastn -query chunk0011.fa -db 'nt.bacteria' -task megablast -out chunk0011.fa.out -outfmt 6
blastn -query chunk0012.fa -db 'nt.bacteria' -task megablast -out chunk0012.fa.out -outfmt 6
blastn -query chunk0013.fa -db 'nt.bacteria' -task megablast -out chunk0013.fa.out -outfmt 6
blastn -query chunk0014.fa -db 'nt.bacteria' -task megablast -out chunk0014.fa.out -outfmt 6
blastn -query chunk0015.fa -db 'nt.bacteria' -task megablast -out chunk0015.fa.out -outfmt 6
blastn -query chunk0016.fa -db 'nt.bacteria' -task megablast -out chunk0016.fa.out -outfmt 6
blastn -query chunk0017.fa -db 'nt.bacteria' -task megablast -out chunk0017.fa.out -outfmt 6
blastn -query chunk0018.fa -db 'nt.bacteria' -task megablast -out chunk0018.fa.out -outfmt 6
blastn -query chunk0019.fa -db 'nt.bacteria' -task megablast -out chunk0019.fa.out -outfmt 6
blastn -query chunk0020.fa -db 'nt.bacteria' -task megablast -out chunk0020.fa.out -outfmt 6
blastn -query chunk0021.fa -db 'nt.bacteria' -task megablast -out chunk0021.fa.out -outfmt 6
blastn -query chunk0022.fa -db 'nt.bacteria' -task megablast -out chunk0022.fa.out -outfmt 6
blastn -query chunk0023.fa -db 'nt.bacteria' -task megablast -out chunk0023.fa.out -outfmt 6
```

tamulauncher



compute node 1

compute node 2

compute node 3

compute node 4

compute node 5

- A convenient way to run a large number (>100) of single-core jobs
- Available for use from the Unix command line and Galaxy (BLAST+)
- Only need to submit one job instead of many small jobs
- Useful for submitting thousands of BLAST jobs

# Biocontainers

# What is a Biocontainer?

- A biocontainer is a container that has one or more bioinformatics software packages installed
- A container is a single image file that contains one or more installed software components
- Docker or Singularity is used to build and access a biocontainer
- A container does not contain the entire OS, just components to complement the host OS for running software installed in the container

## Pros

- Software is already installed with a specific version together with all software dependencies
- The biocontainer is just one file compared to a software module or conda environment which can have thousands of files

## Cons

- The latest software version of a bioinformatics tool may not have a biocontainer available
- Software dependencies within a container may not be the version you want to use

<https://biocontainers-edu.readthedocs.io/en/latest/index.html>

# Using Biocontainers on HPRC Clusters

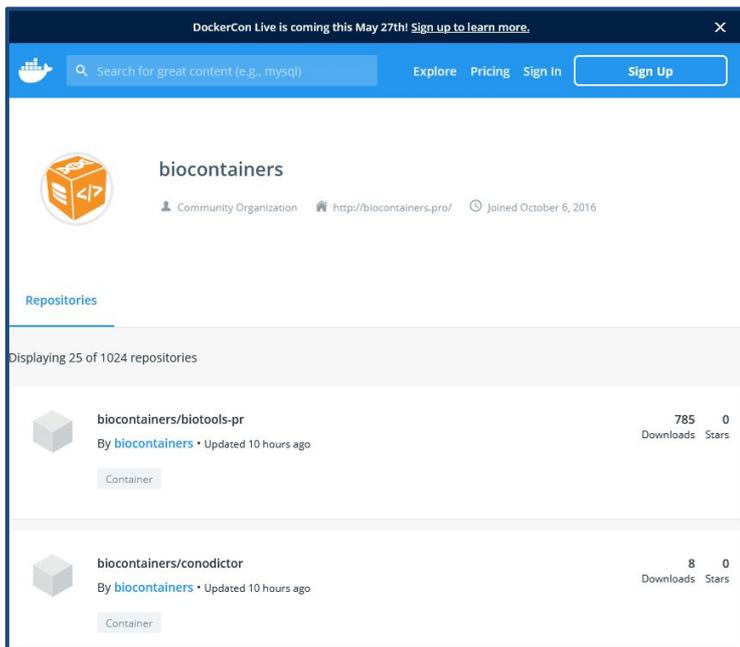
1. Docker is not available on HPRC clusters but Singularity is available
2. Docker images must be converted to a Singularity image
3. Singularity is only available on compute nodes—not login nodes
4. Compute nodes do not have internet access but you can enable a proxy configuration in order to download biocontainers
5. Use VNC portal app or srun to access command line on a compute node in order to convert Docker recipe to a Singularity image
6. Once you have your biocontainer converted to Singularity, you can run it from within a job script

<https://hprc.tamu.edu/kb/Software/Bioinformatics/Biocontainers>

# Finding Biocontainers

<https://hub.docker.com/u/biocontainers>

<https://quay.io>



DockerCon Live is coming this May 27th! [Sign up to learn more.](#)

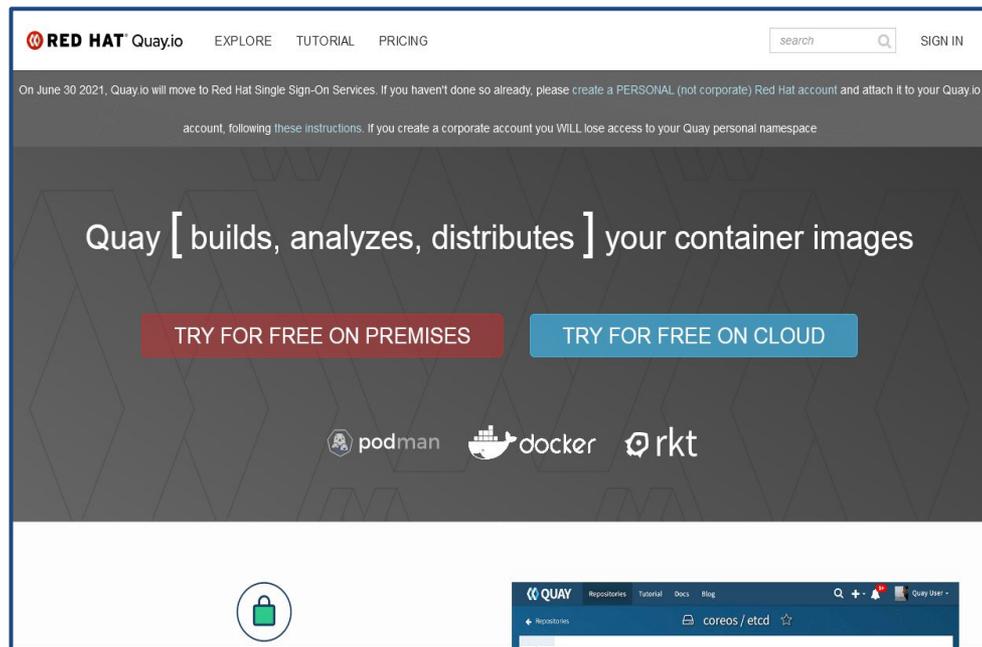
Search for great content (e.g., mysql) Explore Pricing Sign In [Sign Up](#)

 **biocontainers**  
Community Organization <http://biocontainers.pro/> Joined October 6, 2016

Repositories

Displaying 25 of 1024 repositories

Repository	Downloads	Stars
 <b>biocontainers/biotools-pr</b> By <a href="#">biocontainers</a> • Updated 10 hours ago Container	785	0
 <b>biocontainers/conductor</b> By <a href="#">biocontainers</a> • Updated 10 hours ago Container	8	0



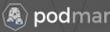
RED HAT Quay.io EXPLORE TUTORIAL PRICING

search SIGN IN

On June 30 2021, Quay.io will move to Red Hat Single Sign-On Services. If you haven't done so already, please create a PERSONAL (not corporate) Red Hat account and attach it to your Quay.io account, following these instructions. If you create a corporate account you WILL lose access to your Quay personal namespace

Quay [ builds, analyzes, distributes ] your container images

[TRY FOR FREE ON PREMISES](#) [TRY FOR FREE ON CLOUD](#)

 podman  docker  rkt



QUAY Repositories Tutorial Docs Blog

Repositories [coreos/etcd](#)

# Build the Singularity Biocontainer

1. Connect to a compute node using the HPRC portal VNC app, **srun** interactive job, or run as a job script

```
srun --time=01:00:00 --mem=14G --ntasks=1 --cpus-per-task=2 --pty bash
```

2. Run the following on the compute node command line to enable proxy for internet connection

```
module load WebProxy
```

3. Images can be large during the conversion from Docker to Singularity. Run the following:

```
export SREGISTRY_DATABASE=$TMPDIR  
export SINGULARITY_CACHEDIR=$TMPDIR
```

4. The following will create a Singularity image from an available Docker container and name it blast\_2.2.31.sif (takes about 4 minutes to download with 2 CPUs and convert the blast container)

```
singularity pull docker://biocontainers/blast:2.2.31
```

<https://hprc.tamu.edu/kb/Software/Singularity/#singularity-pull-examples>

# Singularity Build Time

blast_2.2.31.sif	#SBATCH cpus	#SBATCH memory	time to build .sif file
build 1	2 cores	4 GB	3 min 45 sec
build 2	28 cores	54 GB	2 min

```
#!/bin/bash
#SBATCH --job-name=singularity    # job name
#SBATCH --time=01:00:00         # max job run time dd-hh:mm:ss
#SBATCH --ntasks-per-node=1     # tasks (commands) per compute node
#SBATCH --cpus-per-task=2       # CPUs (threads) per command
#SBATCH --mem=4G                # total memory per node
#SBATCH --output=stdout.%j      # save stdout to file (%j is jobid)
#SBATCH --error=stderr.%j       # save stderr to file (%j is jobid)
```

```
module purge
module load WebProxy
export SREGISTRY_DATABASE=$TMPDIR
export SINGULARITY_CACHEDIR=$TMPDIR
singularity pull docker://biocontainers/blast:2.2.31
```

# Test the Singularity Biocontainer

Enter the following in the same directory as the .sif file to see the help info for the blastp command

```
singularity exec blast_2.2.31.sif blastp -h
```

Or run the following to launch a prompt which you can use to explore the commands available in the container. This is not used to update the image with new or additional software.

```
singularity run blast_2.2.31.sif
```

type `exit` to exit the `Singularity>` prompt

# Example using blastp in a singularity command

These are just examples not available to run.

Example command to run on the compute node command line after either using **srun** or the VNC portal app to launch a job or by putting the command into a job script

```
singularity exec blast_2.2.31.sif blastp -query seqs.fa -db hg19 -out blastout.csv -num_threads 28
```

Or if your .sif file is in a different directory than the working directory

```
singularity exec /sw/hprc/sw/bio/containers/blast_2.2.31.sif blastp -query seqs.fa -db hg19 -out blastout.csv -num_threads 28
```

<https://hprc.tamu.edu/kb/Software/Singularity/#interact-with-container>

# Useful alias Commands for your ~/.bashrc

## **# list files newest to oldest**

```
alias lhl='ls -lsth'
```

```
alias lh='ls -lsth | head'
```

```
alias lhh='ls -lsth | head -20'
```

```
alias lhhh='ls -lsth | head -30'
```

## **# show your running jobs**

```
alias q='squeue -u $USER'
```

```
alias p='psstat -u $USER'
```



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Phone: 979-845-0219

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HPRC Survey

[https://u.tamu.edu/hprc\\_shortcourse\\_survey](https://u.tamu.edu/hprc_shortcourse_survey)

Help us help you. Please include details in your request for support, such as, **Cluster** (ACES, FASTER, Grace, Launch), NetID (UserID), Job information (**JobID**(s)), Location of your jobfile, input/output files, Application, Module(s) loaded, Error messages, etc), and Steps you have taken, so we can reproduce the problem.

