NAME
minimap2 - mapping and alignment between collections of DNA sequences

SYNOPSIS
* Indexing the target sequences (optional):
  minimap2 [-x preset] -d target.mmi target.fa
  minimap2 [-H] [-k kmer] [-w miniWinSize] [-I batchSize] -d target.mmi target.fa

* Long-read alignment with CIGAR:
  minimap2 -a [-x preset] target.mmi query.fa > output.sam
  minimap2 -c [-H] [-k kmer] [-w miniWinSize] [...] target.fa query.fa > output.paf

* Long-read overlap without CIGAR:
  minimap2 -x ava-ont [-t nThreads] target.fa query.fa > output.paf

DESCRIPTION
Minimap2 is a fast sequence mapping and alignment program that can find overlaps between long noisy
reads, or map long reads or their assemblies to a reference genome optionally with detailed alignment (i.e.
CIGAR). At present, it works efficiently with query sequences from a few kilobases to ~100 megabases in
length at a error rate ~15%. Minimap2 outputs in the PAF or the SAM format.

OPTIONS
Indexing options
-k INT Minimizer k-mer length [15]
-w INT Minimizer window size [2/3 of k-mer length]. A minimizer is the smallest k-mer in a window
of w consecutive k-mers.
-H Use homopolymer-compressed (HPC) minimizers. An HPC sequence is constructed by con-
tracting homopolymer runs to a single base. An HPC minimizer is a minimizer on the HPC
sequence.
-I NUM Load at most NUM target bases into RAM for indexing [4G]. If there are more than NUM
bases in target.fa, minimap2 needs to read query.fa multiple times to map it against each batch
of target sequences. NUM may be ending with k/K/m/M/g/G. NB: mapping quality is incor-
rect given a multi-part index.
--idx-no-seq Don’t store target sequences in the index. It saves disk space and memory but the index gener-
ated with this option will not work with -a or -c. When base-level alignment is not requested,
this option is automatically applied.
-d FILE Save the minimizer index of target.fa to FILE [no dump]. Minimap2 indexing is fast. It can
index the human genome in a couple of minutes. If even shorter startup time is desired, use this
option to save the index. Indexing options are fixed in the index file. When an index file is pro-
vided as the target sequences, options -H, -k, -w, -I will be effectively overridden by the
options stored in the index file.

Mapping options
-f FLOAT|INT1,INT2
If fraction, ignore top FLOAT fraction of most frequent minimizers [0.0002]. If integer, ignore
minimizers occurring more than INT1 times. INT2 is only effective in the --sr or -xsr mode,
which sets the threshold for a second round of seeding.
--min-occ-floor INT
Force minimap2 to always use k-mers occurring INT times or less [0]. In effect, the max
occurrence threshold is set to the max{INT, -f}.
-g INT Stop chain elongation if there are no minimizers within INT-bp [10000].
-r INT Bandwidth used in chaining and DP-based alignment [500]. This option approximately con-
trols the maximum gap size.
-n INT Discard chains consisting of <INT number of minimizers [3]
-m INT Discard chains with chaining score <INT [40]. Chaining score equals the approximate number of matching bases minus a concave gap penalty. It is computed with dynamic programming.
-D If query sequence name/length are identical to the target name/length, ignore diagonal anchors. This option also reduces DP-based extension along the diagonal.
-P Retain all chains and don’t attempt to set primary chains. Options -p and -N have no effect when this option is in use.
--dual=yes|no If no, skip query-target pairs wherein the query name is lexicographically greater than the target name [yes]
-X Equivalent to ‘-DP --dual=no --no-long-join’. Primarily used for all-vs-all read overlapping.
-p FLOAT Minimal secondary-to-primary score ratio to output secondary mappings [0.8]. Between two chains overlapping over half of the shorter chain (controlled by --mask-level), the chain with a lower score is secondary to the chain with a higher score. If the ratio of the scores is below FLOAT, the secondary chain will not be outputted or extended with DP alignment later. This option has no effect when -X is applied.
-N INT Output at most INT secondary alignments [5]. This option has no effect when -X is applied.
-G NUM Maximum gap on the reference (effective with -xsplice|--splice). This option also changes the chaining and alignment band width to NUM. Increasing this option slows down spliced alignment. [200k]
-F NUM Maximum fragment length (aka insert size; effective with -xsr|--frag=yes) [800]
-M FLOAT Mark as secondary a chain that overlaps with a better chain by FLOAT or more of the shorter chain [0.5]
--max-chain-skip INT A heuristics that stops chaining early [50]. Minimap2 uses dynamic programming for chaining. The time complexity is quadratic in the number of seeds. This option makes minimap2 exits the inner loop if it repeatedly sees seeds already on chains. Set INT to a large number to switch off this heuristics.
--no-long-join Disable the long gap patching heuristic. When this option is applied, the maximum alignment gap is mostly controlled by -r.
--splice Enable the splice alignment mode.
--sr Enable short-read alignment heuristics. In the short-read mode, minimap2 applies a second round of chaining with a higher minimizer occurrence threshold if no good chain is found. In addition, minimap2 attempts to patch gaps between seeds with ungapped alignment.
--frag=no|yes Whether to enable the fragment mode [no]
--for-only Only map to the forward strand of the reference sequences. For paired-end reads in the forward-reverse orientation, the first read is mapped to forward strand of the reference and the second read to the reverse stand.
--rev-only Only map to the reverse complement strand of the reference sequences.
--heap-sort=no|yes If yes, sort anchors with heap merge, instead of radix sort. Heap merge is faster for short reads, but slower for long reads. [no]

Alignment options
-A INT Matching score [2]
-O INT1[,INT2]  Gap open penalty [4,24]. If INT2 is not specified, it is set to INT1.
-E INT1[,INT2]  Gap extension penalty [2,1]. A gap of length k costs min\{O1+k*E1,O2+k*E2\}. In the splice mode, the second gap penalties are not used.
-C INT  Cost for a non-canonical GT-AG splicing (effective with --splice) [0]
-z INT1[,INT2]  Truncate an alignment if the running alignment score drops too quickly along the diagonal of the DP matrix (diagonal X-drop, or Z-drop) [400,200]. If the drop of score is above INT2, minimap2 will reverse complement the query in the related region and align again to test small inversions. Minimap2 truncates alignment if there is an inversion or the drop of score is greater than INT1. Decrease INT2 to find small inversions at the cost of performance and false positives. Increase INT1 to improves the contiguity of alignment at the cost of poor alignment in the middle.
-s INT  Minimal peak DP alignment score to output [40]. The peak score is computed from the final CIGAR. It is the score of the max scoring segment in the alignment and may be different from the total alignment score.
-u CHAR  How to find canonical splicing sites GT-AG - f: transcript strand; b: both strands; n: no attempt to match GT-AG [n]
--end-bonus INT  Score bonus when alignment extends to the end of the query sequence [0].
--splice-flank=yes/no  Assume the next base to a GT donor site tends to be A/G (91% in human and 92% in mouse) and the preceding base to a AG acceptor tends to be C/T [no]. This trend is evolutionarily conservative, all the way to S. cerevisiae (PMID:18688272). Specifying this option generally leads to higher junction accuracy by several percents, so it is applied by default with --splice. However, the SIRV control does not honor this trend (only ~60%). This option reduces accuracy. If you are benchmarking minimap2 on SIRV data, please add --splice-flank=no to the command line.
--end-seed-pen INT  Drop a terminal anchor if s<log(g)+INT, where s is the local alignment score around the anchor and g the length of the terminal gap in the chain. This option is only effective with --splice. It helps to avoid tiny terminal exons. [6]

Input/output options
-a  Generate CIGAR and output alignments in the SAM format. Minimap2 outputs in PAF by default.
-Q  Ignore base quality in the input file.
-L  Write CIGAR with >65535 operators at the CG tag. Older tools are unable to convert alignments with >65535 CIGAR ops to BAM. This option makes minimap2 SAM compatible with older tools. Newer tools recognizes this tag and reconstruct the real CIGAR in memory.
-R STR  SAM read group line in a format like @RG\tID:foo\tSM:bar [].
-c  Generate CIGAR. In PAF, the CIGAR is written to the ‘cg’ custom tag.
--cs[=STR]  Output the cs tag. STR can be either short or long. If no STR is given, short is assumed. [none]
-Y  In SAM output, use soft clipping for supplementary alignments.
--seed INT  Integer seed for randomizing equally best hits. Minimap2 hashes INT and read name when choosing between equally best hits. [11]
-t INT  Number of threads [3]. Minimap2 uses at most three threads when indexing target sequences, and uses up to INT+1 threads when mapping (the extra thread is for I/O, which is frequently idle and takes little CPU time).

-2  Use two I/O threads during mapping. By default, minimap2 uses one I/O thread. When I/O is slow (e.g. piping to gzip, or reading from a slow pipe), the I/O thread may become the bottleneck. Apply this option to use one thread for input and another thread for output, at the cost of increased peak RAM.

-K NUM  Number of bases loaded into memory to process in a mini-batch [500M]. Similar to option -I, K/M/G/k/m/g suffix is accepted. A large NUM helps load balancing in the multi-threading mode, at the cost of increased memory.

--secondary=yes|no  Whether to output secondary alignments [yes]

--version  Print version number to stdout

Preset options
-x STR  Preset []. This option applies multiple options at the same time. It should be applied before other options because options applied later will overwrite the values set by -x. Available STR are:

map-pb  PacBio/Oxford Nanopore read to reference mapping (-Hk19)

map-ont  Slightly more sensitive for Oxford Nanopore to reference mapping (-k15). For PacBio reads, HPC minimizers consistently leads to faster performance and more sensitive results in comparison to normal minimizers. For Oxford Nanopore data, normal minimizers are better, though not much. The effectiveness of HPC is determined by the sequencing error mode.

asm5  Long assembly to reference mapping (-k19 -w19 -A1 -B19 -O39,81 -E3,1 -s200 -z200 --min-occ-floor=100). Typically, the alignment will not extend to regions with 5% or higher sequence divergence. Only use this preset if the average divergence is far below 5%.


asm20  Long assembly to reference mapping (-k19 -w10 -A1 -B6 -O6,26 -E2,1 -s200 -z200 --min-occ-floor=100). Up to 20% sequence divergence.

ava-pb  PacBio all-vs-all overlap mapping (-Hk19 -Xw5 -m100 -g10000 --max-chain-skip 25).

ava-ont  Oxford Nanopore all-vs-all overlap mapping (-k15 -Xw5 -m100 -g10000 --max-chain-skip 25). Similarly, the major difference from ava-pb is that this preset is not using HPC minimizers.

splice  Long-read spliced alignment (-k15 -w5 --splice -g2000 -G200k -A1 -B2 -O2,32 -E1,0 -C9 -z200 -ub --splice-flank=yes). In the splice mode, 1) long deletions are taken as introns and represented as the ‘N’ CIGAR operator; 2) long insertions are disabled; 3) deletion and insertion gap costs are different during chaining; 4) the computation of the ‘ms’ tag ignores introns to demote hits to pseudogenes.

sr  Short single-end reads without splicing (-k21 -w11 --sr --frag=yes -A2 -B8 -O12,32 -E2,1 -r50 -p.5 -N20 -f1000,5000 -n2 -m20 -s40 -g200 -2K50m --heap-sort=yes --secondary=no).

Miscellaneous options
--no-kalloc
Use the libc default allocator instead of the kalloc thread-local allocator. This debugging option is mostly used with Valgrind to detect invalid memory accesses. Minimap2 runs slower with this option, especially in the multi-threading mode.

--print-qname
Print query names to stderr, mostly to see which query is crashing minimap2.

--print-seeds
Print seed positions to stderr, for debugging only.

OUTPUT FORMAT
Minimap2 outputs mapping positions in the Pairwise mApping Format (PAF) by default. PAF is a TAB-delimited text format with each line consisting of at least 12 fields as are described in the following table:

<table>
<thead>
<tr>
<th>Col</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>string</td>
<td>Query sequence name</td>
</tr>
<tr>
<td>2</td>
<td>int</td>
<td>Query sequence length</td>
</tr>
<tr>
<td>3</td>
<td>int</td>
<td>Query start coordinate (0-based)</td>
</tr>
<tr>
<td>4</td>
<td>int</td>
<td>Query end coordinate (0-based)</td>
</tr>
<tr>
<td>5</td>
<td>char</td>
<td><code>+' if query/target on the same strand; </code>-` if opposite</td>
</tr>
<tr>
<td>6</td>
<td>string</td>
<td>Target sequence name</td>
</tr>
<tr>
<td>7</td>
<td>int</td>
<td>Target sequence length</td>
</tr>
<tr>
<td>8</td>
<td>int</td>
<td>Target start coordinate on the original strand</td>
</tr>
<tr>
<td>9</td>
<td>int</td>
<td>Target end coordinate on the original strand</td>
</tr>
<tr>
<td>10</td>
<td>int</td>
<td>Number of matching bases in the mapping</td>
</tr>
<tr>
<td>11</td>
<td>int</td>
<td>Number bases, including gaps, in the mapping</td>
</tr>
<tr>
<td>12</td>
<td>int</td>
<td>Mapping quality (0-255 with 255 for missing)</td>
</tr>
</tbody>
</table>

When alignment is available, column 11 gives the total number of sequence matches, mismatches and gaps in the alignment; column 10 divided by column 11 gives the BLAST-like alignment identity. When alignment is unavailable, these two columns are approximate. PAF may optionally have additional fields in the SAM-like typed key-value format. Minimap2 may output the following tags:

<table>
<thead>
<tr>
<th>Tag</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tp</td>
<td>A</td>
<td>Type of aln: P/primary, S/secondary and I/i/inversion</td>
</tr>
<tr>
<td>cm</td>
<td>i</td>
<td>Number of minimizers on the chain</td>
</tr>
<tr>
<td>s1</td>
<td>i</td>
<td>Chaining score</td>
</tr>
<tr>
<td>s2</td>
<td>i</td>
<td>Chaining score of the best secondary chain</td>
</tr>
<tr>
<td>NM</td>
<td>i</td>
<td>Total number of mismatches and gaps in the alignment</td>
</tr>
<tr>
<td>AS</td>
<td>i</td>
<td>DP alignment score</td>
</tr>
<tr>
<td>ms</td>
<td>i</td>
<td>DP score of the max scoring segment in the alignment</td>
</tr>
<tr>
<td>nn</td>
<td>i</td>
<td>Number of ambiguous bases in the alignment</td>
</tr>
<tr>
<td>ts</td>
<td>A</td>
<td>Transcript strand (splice mode only)</td>
</tr>
<tr>
<td>cg</td>
<td>Z</td>
<td>CIGAR string (only in PAF)</td>
</tr>
<tr>
<td>cs</td>
<td>Z</td>
<td>Difference string</td>
</tr>
</tbody>
</table>

The cs tag encodes difference sequences in the short form or the entire query AND reference sequences in the long form. It consists of a series of operations:
### Op Regex Description

<table>
<thead>
<tr>
<th>Op</th>
<th>Regex</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>=</td>
<td>[ACGTN]+</td>
<td>Identical sequence (long form)</td>
</tr>
<tr>
<td>:</td>
<td>[0-9]+</td>
<td>Identical sequence length</td>
</tr>
<tr>
<td>*</td>
<td>[acgtn][acgtn]</td>
<td>Substitution: ref to query</td>
</tr>
<tr>
<td>+</td>
<td>[acgtn]+</td>
<td>Insertion to the reference</td>
</tr>
<tr>
<td>-</td>
<td>[acgtn]+</td>
<td>Deletion from the reference</td>
</tr>
<tr>
<td>˜</td>
<td>[acgtn][2][0-9]+[acgtn][2]</td>
<td>Intron length and splice signal</td>
</tr>
</tbody>
</table>

### LIMITATIONS

* Minimap2 may produce suboptimal alignments through long low-complexity regions where seed positions may be suboptimal. This should not be a big concern because even the optimal alignment may be wrong in such regions.

* Minimap2 requires SSE2 or NEON instructions to compile. It is possible to add non-SSE2/NEON support, but it would make minimap2 slower by several times.

### SEE ALSO

miniasm(1), minimap(1), bwa(1).