

The biomaRt user's guide

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Contents

1	Introduction	2
2	Selecting a BioMart database and dataset	3
3	How to build a biomaRt query	5
4	Examples of biomaRt queries	7
4.1	Task 1: Annotate a set of Affymetrix identifiers with HUGO symbol and chromosomal locations of corresponding genes . .	7
4.2	Task 2: Annotate a set of EntrezGene identifiers with GO annotation	8
4.3	Task 3: Retrieve all HUGO gene symbols of genes that are located on chromosomes 1,2 or Y , and are associated with one the following GO terms: "GO:0051330","GO:0000080","GO:0000114","GO:0000082" (here we'll use more than one filter)	8
4.4	Task 4: Annotate set of identifiers with INTERPRO protein domain identifiers	9
4.5	Task 5: Select all Affymetrix identifiers on the hgu133plus2 chip and Ensembl gene identifiers for genes located on chromosome 16 between basepair 1100000 and 1250000.	9
4.6	Task 6: Retrieve all entrezgene identifiers and HUGO gene symbols of genes which have a "MAP kinase activity" GO term associated with it.	10

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4.7	Task 7: Given a set of EntrezGene identifiers, retrieve 100bp upstream promoter sequences	11
4.8	Task 8: Retrieve all 5' UTR sequences of all genes that are located on chromosome 3 between the positions 185514033 and 185535839	12
4.9	Task 9: Retrieve protein sequences for a given list of EntrezGene identifiers	12
4.10	Task 10: Retrieve known SNPs located on the human chromosome 8 between positions 148350 and 148612	12
4.11	Task 11: Given the human gene TP53, retrieve the human chromosomal location of this gene and also retrieve the chromosomal location and RefSeq id of it's homolog in mouse.	13
5	Using archived versions of Ensembl	14
6	Using a BioMart other than Ensembl	15
7	biomaRt helper functions	16
7.1	exportFASTA	16
7.2	Finding out more information on filters	16
7.2.1	filterType	16
7.2.2	filterOptions	16
7.3	Attribute Pages	17
8	Local BioMart databases	20
8.1	Minimum requirements for local database installation	21
9	Session Info	21

1 Introduction

In recent years a wealth of biological data has become available in public data repositories. Easy access to these valuable data resources and firm integration with data analysis is needed for comprehensive bioinformatics data analysis. The *biomaRt* package, provides an interface to a growing collection of databases implementing the BioMart software suite (<http://www.biomart.org>). The package enables retrieval of large amounts of data in a uniform way without the need to know the underlying database schemas or write complex SQL queries. Examples of BioMart databases are Ensembl,

Uniprot and HapMap. These major databases give biomaRt users direct access to a diverse set of data and enable a wide range of powerful online queries from R.

2 Selecting a BioMart database and dataset

Every analysis with *biomaRt* starts with selecting a BioMart database to use. A first step is to check which BioMart web services are available. The function `listMarts` will display all available BioMart web services

```
> library("biomaRt")
> listMarts()
```

	biomart	version
1	ensembl	ENSEMBL 56 GENES (SANGER UK)
2	snp	ENSEMBL 56 VARIATION (SANGER UK)
3	functional_genomics	ENSEMBL 56 FUNCTIONAL GENOMICS (SANGER UK)
4	vega	VEGA 36 (SANGER UK)
5	msd	MSD PROTOTYPE (EBI UK)
6	bacterial_mart_3	ENSEMBL BACTERIA 3 (EBI UK)
7	fungus_mart_3	ENSEMBL FUNGAL 3 (EBI UK)
8	metazoa_mart_3	ENSEMBL METAZOA 3 (EBI UK)
9	plant_mart_3	ENSEMBL PLANT 3 (EBI UK)
10	protist_mart_3	ENSEMBL PROTISTS 3 (EBI UK)
11	htgt	HIGH THROUGHPUT GENE TARGETING AND TRAPPING (SANGER UK)
12	REACTOME	REACTOME (CSHL US)
13	wormbase_current	WORMBASE (CSHL US)
14	dicty	DICTYBASE (NORTHWESTERN US)
15	rgd_mart	RGD GENES (MCW US)
16	ipi_rat_mart	RGD IPI MART (MCW US)
17	SSLP_mart	RGD MICROSATELLITE MARKERS (MCW US)
18	g4public	HGNC (EBI UK)
19	pride	PRIDE (EBI UK)
20	intermart-1	INTERPRO (EBI UK)
21	uniprot_mart	UNIPROT (EBI UK)
22	ensembl_expressionmart_48	EURATMART (EBI UK)
23	biomartDB	PARAMECIUM GENOME (CNRS FRANCE)
24	Eurexpress Biomart	EUREXPRESS (MRC EDINBURGH UK)
25	pepseekerGOLD_mart06	PEPSEEKER (UNIVERSITY OF MANCHESTER UK)
26	Potato_01	DB POTATO (INTERNATIONAL POTATO CENTER-CIP PERU)
27	Sweetpotato_01	DB SWEETPOTATO (INTERNATIONAL POTATO CENTER-CIP PERU)
28	Pancreatic_Expression	PANCREATIC EXPRESSION DATABASE (INSTITUTE OF CANCER UK)
29	ENSEMBL_MART_ENSEMBL	GRAMENE 30 ENSEMBL GENES
30	GRAMENE_MARKER_30	GRAMENE 30 MARKERS
31	GRAMENE_MAP_30	GRAMENE 30 MAPPINGS
32	QTL_MART	GRAMENE 30 QTL DB

Note: if the function `useMart` runs into proxy problems you should set your proxy first before calling any biomaRt functions. You can do this using the `Sys.putenv` command:

```
Sys.putenv("http_proxy" = "http://my.proxy.org:9999")
```

The `useMart` function can now be used to connect to a specified BioMart database, this must be a valid name given by `listMarts`. In the next example we choose to query the Ensembl BioMart database.

```
> ensembl = useMart("ensembl")
```

BioMart databases can contain several datasets, for Ensembl every species is a different dataset. In a next step we look at which datasets are available in the selected BioMart by using the function `listDatasets`.

```
> listDatasets(ensembl)
```

	dataset	description	version
1	oanatinus_gene_ensembl	Ornithorhynchus anatinus genes (OANA5)	OANA5
2	tguttata_gene_ensembl	Taeniopygia guttata genes (taeGut3.2.4)	taeGut3.2.4
3	cporcellus_gene_ensembl	Cavia porcellus genes (cavPor3)	cavPor3
4	gaculeatus_gene_ensembl	Gasterosteus aculeatus genes (BROADS1)	BROADS1
5	lafricana_gene_ensembl	Loxodonta africana genes (loxAfr2)	loxAfr2
6	mlucifugus_gene_ensembl	Myotis lucifugus genes (myoLuc1)	myoLuc1
7	hsapiens_gene_ensembl	Homo sapiens genes (GRCh37)	GRCh37
8	choffmanni_gene_ensembl	Choloepus hoffmanni genes (choHof1)	choHof1
9	csavignyi_gene_ensembl	Ciona savignyi genes (CSAV2.0)	CSAV2.0
10	fcatus_gene_ensembl	Felis catus genes (CAT)	CAT
11	rnorvegicus_gene_ensembl	Rattus norvegicus genes (RGSC3.4)	RGSC3.4
12	ggallus_gene_ensembl	Gallus gallus genes (WASHUC2)	WASHUC2
13	tbelangeri_gene_ensembl	Tupaia belangeri genes (tupBel1)	tupBel1
14	xtropicalis_gene_ensembl	Xenopus tropicalis genes (JGI4.1)	JGI4.1
15	ecaballus_gene_ensembl	Equus caballus genes (EquCab2)	EquCab2
16	cjacchus_gene_ensembl	Callithrix jacchus genes (calJac3)	calJac3
17	drerio_gene_ensembl	Danio rerio genes (Zv8)	Zv8
18	stridecemlineatus_gene_ensembl	Spermophilus tridecemlineatus genes (speTri1)	speTri1
19	tnigroviridis_gene_ensembl	Tetraodon nigroviridis genes (TETRAODON8.0)	TETRAODON8.0
20	ttruncatus_gene_ensembl	Tursiops truncatus genes (turTru1)	turTru1
21	scerevisiae_gene_ensembl	Saccharomyces cerevisiae genes (SGD1.01)	SGD1.01
22	celegans_gene_ensembl	Caenorhabditis elegans genes (WS200)	WS200
23	mmulatta_gene_ensembl	Macaca mulatta genes (MMUL_1.0)	MMUL_1.0
24	pvampyrus_gene_ensembl	Pteropus vampyrus genes (pteVam1)	pteVam1
25	mdomestica_gene_ensembl	Monodelphis domestica genes (monDom5)	monDom5
26	vpacos_gene_ensembl	Vicugna pacos genes (vicPac1)	vicPac1
27	acarolinensis_gene_ensembl	Anolis carolinensis genes (AnoCar1.0)	AnoCar1.0
28	tsyrichta_gene_ensembl	Tarsius syrichta genes (tarSyr1)	tarSyr1
29	ogarnettii_gene_ensembl	Otolemur garnettii genes (otoGar1)	otoGar1
30	trubripes_gene_ensembl	Takifugu rubripes genes (FUGU4.0)	FUGU4.0
31	dmelanogaster_gene_ensembl	Drosophila melanogaster genes (BDGP5.13)	BDGP5.13
32	eeuropaeus_gene_ensembl	Erinaceus europaeus genes (eriEur1)	eriEur1
33	mmurinus_gene_ensembl	Microcebus murinus genes (micMur1)	micMur1
34	olatipes_gene_ensembl	Oryzias latipes genes (HdrR)	HdrR
35	etelfairi_gene_ensembl	Echinops telfairi genes (TENREC)	TENREC
36	cintestinalis_gene_ensembl	Ciona intestinalis genes (JGI2)	JGI2
37	ptroglodytes_gene_ensembl	Pan troglodytes genes (CHIMP2.1)	CHIMP2.1
38	oprinceps_gene_ensembl	Ochotona princeps genes (OchPri2.0)	OchPri2.0

39	ggorilla_gene_ensembl	Gorilla gorilla genes (gorGor1)	gorGor1
40	dordii_gene_ensembl	Dipodomys ordii genes (dipOrd1)	dipOrd1
41	ppygmaeus_gene_ensembl	Pongo pygmaeus abelii genes (PPYG2)	PPYG2
42	sscrofa_gene_ensembl	Sus scrofa genes (Sscrofa9)	Sscrofa9
43	mmusculus_gene_ensembl	Mus musculus genes (NCBIM37)	NCBIM37
44	ocuniculus_gene_ensembl	Oryctolagus cuniculus genes (RABBIT)	RABBIT
45	saraneus_gene_ensembl	Sorex araneus genes (sorAra1)	sorAra1
46	dnovemcinctus_gene_ensembl	Dasypus novemcinctus genes (dasNov2)	dasNov2
47	pcapensis_gene_ensembl	Procapia capensis genes (proCap1)	proCap1
48	btaurus_gene_ensembl	Bos taurus genes (Btau_4.0)	Btau_4.0
49	meugenii_gene_ensembl	Macropus eugenii genes (Meug_1.0)	Meug_1.0
50	cfamiliaris_gene_ensembl	Canis familiaris genes (CanFam_2.0)	CanFam_2.0

To select a dataset we can update the `Mart` object using the function `useDataset`. In the example below we choose to use the `hsapiens` dataset.

```
ensembl = useDataset("hsapiens_gene_ensembl", mart=ensembl)
```

Or alternatively if the dataset one wants to use is known in advance, we can select a BioMart database and dataset in one step by:

```
> ensembl = useMart("ensembl", dataset = "hsapiens_gene_ensembl")
```

3 How to build a biomaRt query

The `getBM` function has three arguments that need to be introduced: filters, attributes and values. *Filters* define a restriction on the query. For example you want to restrict the output to all genes located on the human X chromosome then the filter *chromosome_name* can be used with value 'X'. The `listFilters` function shows you all available filters in the selected dataset.

```
> filters = listFilters(ensembl)
> filters[1:5, ]
```

	name	description
1	chromosome_name	Chromosome name
2	start	Gene Start (bp)
3	end	Gene End (bp)
4	band_start	Band Start
5	band_end	Band End

Attributes define the values we are interested in to retrieve. For example we want to retrieve the gene symbols or chromosomal coordinates. The `listAttributes` function displays all available attributes in the selected dataset.

```
> attributes = listAttributes(ensembl)
> attributes[1:5, ]
```

	name	description
1	ensembl_gene_id	Ensembl Gene ID
2	ensembl_transcript_id	Ensembl Transcript ID
3	ensembl_peptide_id	Ensembl Protein ID
4	canonical_transcript_stable_id	Canonical transcript stable ID(s)
5	description	Description

The `getBM` function is the main query function in `biomaRt`. It has four main arguments:

- `attributes`: is a vector of attributes that one wants to retrieve (= the output of the query).
- `filters`: is a vector of filters that one will use as input to the query.
- `values`: a vector of values for the filters. In case multiple filters are in use, the `values` argument requires a list of values where each position in the list corresponds to the position of the filters in the `filters` argument (see examples below).
- `mart`: is an object of class `Mart`, which is created by the `useMart` function.

Note: for some frequently used queries to Ensembl a set of wrapper are functions available as will be described in the sections below. These wrapper functions are: `getGene`, `getSequence`, `getGO`, `getHomolog`, `getSNP`. All these functions call the `getBM` function with hard coded filter and attribute names.

Now that we selected a BioMart database and dataset, and know about attributes, filters, and the values for filters; we can build a `biomaRt` query. Let's make an easy query for the following problem: We have a list of Affymetrix identifiers from the `u133plus2` platform and we want to retrieve the corresponding EntrezGene identifiers using the Ensembl mappings. The `u133plus2` platform will be the filter for this query and as values for this filter we use our list of Affymetrix identifiers. As output (attributes) for the query we want to retrieve the EntrezGene and `u133plus2` identifiers so we get a mapping of these two identifiers as a result. The exact names that we

will have to use to specify the attributes and filters can be retrieved with the `listAttributes` and `listFilters` function respectively. Let's now run the query:

```
> affyids = c("202763_at", "209310_s_at", "207500_at")
> getBM(attributes = c("affy_hg_u133_plus_2", "entrezgene"), filters = "affy_hg_u133_plus_2",
+       values = affyids, mart = ensembl)
```

	affy_hg_u133_plus_2	entrezgene
1	202763_at	836
2	202763_at	NA
3	209310_s_at	837
4	209310_s_at	NA
5	207500_at	838
6	207500_at	NA

4 Examples of biomaRt queries

In the sections below a variety of example queries are described. Every example is written as a task, and we have to come up with a biomaRt solution to the problem.

4.1 Task 1: Annotate a set of Affymetrix identifiers with HUGO symbol and chromosomal locations of corresponding genes

We have a list of Affymetrix hgu133plus2 identifiers and we would like to retrieve the HUGO gene symbols, chromosome names, start and end positions and the bands of the corresponding genes. The `listAttributes` and the `listFilters` functions give us an overview of the available attributes and filters and we look in those lists to find the corresponding attribute and filter names we need. For this query we'll need the following attributes: `hgnc_symbol`, `chromosome_name`, `start_position`, `end_position`, `band` and `affy_hg_u133_plus_2` (as we want these in the output to provide a mapping with our original Affymetrix input identifiers. There is one filter in this query which is the `affy_hg_u133_plus_2` filter as we use a list of Affymetrix identifiers as input. Putting this all together in the `getBM` and performing the query gives:

```
> affyids = c("202763_at", "209310_s_at", "207500_at")
> getBM(attributes = c("affy_hg_u133_plus_2", "hgnc_symbol", "chromosome_name", "start_position",
+       "end_position", "band"), filters = "affy_hg_u133_plus_2", values = affyids, mart = ensembl)
```

	affy_hg_u133_plus_2	hgnc_symbol	chromosome_name	start_position	end_position	band
1	202763_at	CASP3	4	185548850	185570629	q35.1
2	209310_s_at	CASP4	11	104813594	104840163	q22.3
3	207500_at	CASP5	11	104864962	104893895	q22.3

4.2 Task 2: Annotate a set of EntrezGene identifiers with GO annotation

In this task we start out with a list of EntrezGene identifiers and we want to retrieve GO identifiers related to biological processes that are associated with these entrezgene identifiers. Again we look at the output of `listAttributes` and `listFilters` to find the filter and attributes we need. Then we construct the following query:

```
> entrez = c("673", "837")
> getBM(attributes = c("entrezgene", "go_biological_process_id"), filters = "entrezgene", values = entrez,
+       mart = ensembl)
```

	entrezgene	go_biological_process_id
1	673	GO:0006916
2	673	GO:0009887
3	673	GO:0007264
4	673	GO:0006468
5	673	GO:0007242
6	673	GO:0007165
7	673	GO:0000165
8	673	GO:0051291
9	837	GO:0042981
10	837	GO:0006917
11	837	GO:0006508
12	837	GO:0006915

4.3 Task 3: Retrieve all HUGO gene symbols of genes that are located on chromosomes 1,2 or Y , and are associated with one the following GO terms: "GO:0051330","GO:0000080","GO:0000114","GO:0000082" (here we'll use more than one filter)

The `getBM` function enables you to use more than one filter. In this case the filter argument should be a vector with the filter names. The values should be a list, where the first element of the list corresponds to the first filter and the second list element to the second filter and so on. The elements of this list are vectors containing the possible values for the corresponding filters.

```
go=c("GO:0051330","GO:0000080","GO:0000114")
chrom=c(1,2,"Y")
getBM(attributes= "hgnc_symbol",
      filters=c("go","chromosome_name"),
      values=list(go,chrom), mart=ensembl)
```

	hgnc_symbol
1	PPP1CB
2	SPDYA
3	ACVR1
4	CUL3


```

5      RCC1
6      CDC7
7      RHOU

```

4.4 Task 4: Annotate set of identifiers with INTERPRO protein domain identifiers

In this example we want to annotate the following two RefSeq identifiers: NM_005359 and NM_000546 with INTERPRO protein domain identifiers and a description of the protein domains.

```

> refseqids = c("NM_005359", "NM_000546")
> ipro = getBM(attributes = c("refseq_dna", "interpro", "interpro_description"), filters =
+   values = refseqids, mart = ensembl)

```

```

ipro
  refseq_dna interpro      interpro_description
1 NM_000546 IPR002117      p53 tumor antigen
2 NM_000546 IPR010991      p53, tetramerisation
3 NM_000546 IPR011615      p53, DNA-binding
4 NM_000546 IPR013872 p53 transactivation domain (TAD)
5 NM_000546 IPR000694      Proline-rich region
6 NM_005359 IPR001132      MAD homology 2, Dwarfina-type
7 NM_005359 IPR003619      MAD homology 1, Dwarfina-type
8 NM_005359 IPR013019      MAD homology, MH1

```

4.5 Task 5: Select all Affymetrix identifiers on the hgu133plus2 chip and Ensembl gene identifiers for genes located on chromosome 16 between basepair 1100000 and 1250000.

In this example we will again use multiple filters: chromosome_name, start, and end as we filter on these three conditions. Note that when a chromosome name, a start position and an end position are jointly used as filters, the BioMart webservice interprets this as return everything from the given chromosome between the given start and end positions.

```

> getBM(c("affy_hg_u133_plus_2", "ensembl_gene_id"), filters = c("chromosome_name", "start",
+   "end"), values = list(16, 1100000, 1250000), mart = ensembl)

```

```

  affy_hg_u133_plus_2 ensembl_gene_id
1                    ENSG00000227086
2      214555_at      ENSG00000162009
3                    ENSG00000184471
4                    ENSG00000235846
5      205845_at      ENSG00000196557
6                    ENSG00000181791

```

4.6 Task 6: Retrieve all entrezgene identifiers and HUGO gene symbols of genes which have a "MAP kinase activity" GO term associated with it.

The GO identifier for MAP kinase activity is GO:0004707. In our query we will use go as filter and entrezgene and hgnc_symbol as attributes. Here's the query:

```
> getBM(c("entrezgene", "hgnc_symbol"), filters = "go", values = "GO:0004707", mart = ensembl)
```

	entrezgene	hgnc_symbol
1	5596	MAPK4
2	5594	MAPK1
3	NA	MAPK1
4	NA	
5	5597	MAPK6
6	5602	MAPK10
7	NA	MAPK10
8	5598	MAPK7
9	NA	MAPK7
10	51701	NLK
11	NA	NLK
12	8621	CDC2L5
13	NA	CDC2L5
14	5595	MAPK3
15	NA	MAPK3
16	NA	MAPK8
17	5599	MAPK8
18	1017	CDK2
19	225689	MAPK15
20	NA	MAPK15
21	51755	CRKRS
22	NA	CRKRS
23	6300	MAPK12
24	NA	MAPK12
25	5600	MAPK11
26	NA	MAPK11
27	5601	MAPK9
28	1432	MAPK14
29	NA	MAPK14
30	5603	MAPK13
31	NA	MAPK13
32	100133692	CDC2L1
33	100133692	CDC2L2
34	100294398	CDC2L1
35	100294398	CDC2L2
36	NA	CDC2L1
37	NA	CDC2L2
38	984	CDC2L1
39	984	CDC2L2
40	728642	CDC2L1
41	728642	CDC2L2

4.7 Task 7: Given a set of EntrezGene identifiers, retrieve 100bp upstream promoter sequences

All sequence related queries to Ensembl are available through the `getSequence` wrapper function. `getBM` can also be used directly to retrieve sequences but this can get complicated so using `getSequence` is recommended. Sequences can be retrieved using the `getSequence` function either starting from chromosomal coordinates or identifiers. The chromosome name can be specified using the *chromosome* argument. The *start* and *end* arguments are used to specify *start* and *end* positions on the chromosome. The type of sequence returned can be specified by the *seqType* argument which takes the following values: 'cdna'; 'peptide' for protein sequences; '3utr' for 3' UTR sequences; '5utr' for 5' UTR sequences; 'gene_exon' for exon sequences only; 'transcript_exon' for transcript specific exonic sequences only; 'transcript_exon_intron' gives the full unspliced transcript, that is exons + introns; 'gene_exon_intron' gives the exons + introns of a gene; 'coding' gives the coding sequence only; 'coding_transcript_flank' gives the flanking region of the transcript including the UTRs, this must be accompanied with a given value for the upstream or downstream attribute; 'coding_gene_flank' gives the flanking region of the gene including the UTRs, this must be accompanied with a given value for the upstream or downstream attribute; 'transcript_flank' gives the flanking region of the transcript excluding the UTRs, this must be accompanied with a given value for the upstream or downstream attribute; 'gene_flank' gives the flanking region of the gene excluding the UTRs, this must be accompanied with a given value for the upstream or downstream attribute.

In MySQL mode the `getSequence` function is more limited and the sequence that is returned is the 5' to 3'+ strand of the genomic sequence, given a chromosome, as start and an end position.

Task 4 requires us to retrieve 100bp upstream promoter sequences from a set of EntrezGene identifiers. The *type* argument in `getSequence` can be thought of as the filter in this query and uses the same input names given by `listFilters`. In our query we use `entrezgene` for the *type* argument. Next we have to specify which type of sequences we want to retrieve, here we are interested in the sequences of the promoter region, starting right next to the coding start of the gene. Setting the *seqType* to `coding_gene_flank` will give us what we need. The *upstream* argument is used to specify how many bp of upstream sequence we want to retrieve, here we'll retrieve a rather short sequence of 100bp. Putting this all together in `getSequence` gives:

```
> entrez = c("673", "7157", "837")
> getSequence(id = entrez, type = "entrezgene", seqType = "coding_gene_flank", upstream = 100,
+             mart = ensembl)
```

4.8 Task 8: Retrieve all 5' UTR sequences of all genes that are located on chromosome 3 between the positions 185514033 and 185535839

As described in the previous task `getSequence` can also use chromosomal coordinates to retrieve sequences of all genes that lie in the given region. We also have to specify which type of identifier we want to retrieve together with the sequences, here we choose for `entrezgene` identifiers.

```
> utr5 = getSequence(chromosome = 3, start = 185514033, end = 185535839, type = "entrezgene",
+                    seqType = "5utr", mart = ensembl)
> utr5
```

```

          V1          V2
.....GAAGCGGTGGC .... 1981
```

4.9 Task 9: Retrieve protein sequences for a given list of EntrezGene identifiers

In this task the `type` argument specifies which type of identifiers we are using. To get an overview of other valid identifier types we refer to the `listFilters` function.

```
> protein = getSequence(id = c(100, 5728), type = "entrezgene", seqType = "peptide", mart = ensembl)
> protein
```

```

peptide      entrezgene
MAQTPAFDKPKVEL ...    100
MTAIIKEIVSRNKRR ...    5728
```

4.10 Task 10: Retrieve known SNPs located on the human chromosome 8 between positions 148350 and 148612

For this example we'll first have to connect to a different BioMart database, namely `snp`.

```
> snpmart = useMart("snp", dataset = "hsapiens_snp")
```

The `listAttributes` and `listFilters` functions give us an overview of the available attributes and filters. From these we need: `refsnp_id`, `allele`, `chrom_start` and `chrom_strand` as attributes; and as filters we'll use:

chrom_start, chrom_end and chr_name. Note that when a chromosome name, a start position and an end position are jointly used as filters, the BioMart webservice interprets this as return everything from the given chromosome between the given start and end positions. Putting our selected attributes and filters into getBM gives:

```
> getBM(c("refsnp_id", "allele", "chrom_start", "chrom_strand"), filters = c("chr_name", "chrom_start",
+ "chrom_end"), values = list(8, 148350, 148612), mart = snpmart)
```

	refsnp_id	allele	chrom_start	chrom_strand
1	rs1134195	G/T	148394	-1
2	rs4046274	C/A	148394	1
3	rs4046275	A/G	148411	1
4	rs13291	C/T	148462	1
5	rs1134192	G/A	148462	-1
6	rs4046276	C/T	148462	1
7	rs12019378	T/G	148471	1
8	rs1134191	C/T	148499	-1
9	rs4046277	G/A	148499	1
10	rs11136408	G/A	148525	1
11	rs1134190	C/T	148533	-1
12	rs4046278	G/A	148533	1
13	rs1134189	G/A	148535	-1
14	rs3965587	C/T	148535	1
15	rs1134187	G/A	148539	-1
16	rs1134186	T/C	148569	1
17	rs4378731	G/A	148601	1

4.11 Task 11: Given the human gene TP53, retrieve the human chromosomal location of this gene and also retrieve the chromosomal location and RefSeq id of it's homolog in mouse.

The `getLDS` (Get Linked Dataset) function provides functionality to link 2 BioMart datasets which each other and construct a query over the two datasets. In Ensembl, linking two datasets translates to retrieving homology data across species. The usage of `getLDS` is very similar to `getBM`. The linked dataset is provided by a separate `Mart` object and one has to specify filters and attributes for the linked dataset. Filters can either be applied to both datasets or to one of the datasets. Use the `listFilters` and `listAttributes` functions on both `Mart` objects to find the filters and attributes for each dataset (species in Ensembl). The attributes and filters of the linked dataset can be specified with the `attributesL` and `filtersL` arguments. Entering all this information into `getLDS` gives:

```
human = useMart("ensembl", dataset = "hsapiens_gene_ensembl")
mouse = useMart("ensembl", dataset = "mmusculus_gene_ensembl")
getLDS(attributes = c("hgnc_symbol", "chromosome_name", "start_position"),
        filters = "hgnc_symbol", values = "TP53", mart = human,
        attributesL = c("refseq_dna", "chromosome_name", "start_position"), martL = mouse)
```

```

      V1 V2      V3      V4 V5      V6
1 TP53 17 7512464 NM_011640 11 69396600

```

5 Using archived versions of Ensembl

It is possible to query archived versions of Ensembl through *biomaRt*. The steps below show how to do this. First we list the available Ensembl archives by using the `listMarts` function and setting the archive attribute to `TRUE`.

```
> listMarts(archive = TRUE)
```

	biomart	version
1	ensembl_mart_51	Ensembl 51
2	snp_mart_51	SNP 51
3	vega_mart_51	Vega 32
4	ensembl_mart_50	Ensembl 50
5	snp_mart_50	SNP 50
6	vega_mart_50	Vega 32
7	ensembl_mart_49	ENSEMBL GENES 49 (SANGER)
8	genomic_features_mart_49	Genomic Features
9	snp_mart_49	SNP
10	vega_mart_49	Vega
11	ensembl_mart_48	ENSEMBL GENES 48 (SANGER)
12	genomic_features_mart_48	Genomic Features
13	snp_mart_48	SNP
14	vega_mart_48	Vega
15	ensembl_mart_47	ENSEMBL GENES 47 (SANGER)
16	genomic_features_mart_47	Genomic Features
17	snp_mart_47	SNP
18	vega_mart_47	Vega
19	compara_mart_homology_47	Compara homology
20	compara_mart_multiple_ga_47	Compara multiple alignments
21	compara_mart_pairwise_ga_47	Compara pairwise alignments
22	ensembl_mart_46	ENSEMBL GENES 46 (SANGER)
23	genomic_features_mart_46	Genomic Features
24	snp_mart_46	SNP
25	vega_mart_46	Vega
26	compara_mart_homology_46	Compara homology
27	compara_mart_multiple_ga_46	Compara multiple alignments
28	compara_mart_pairwise_ga_46	Compara pairwise alignments
29	ensembl_mart_45	ENSEMBL GENES 45 (SANGER)
30	snp_mart_45	SNP
31	vega_mart_45	Vega
32	compara_mart_homology_45	Compara homology
33	compara_mart_multiple_ga_45	Compara multiple alignments
34	compara_mart_pairwise_ga_45	Compara pairwise alignments
35	ensembl_mart_44	ENSEMBL GENES 44 (SANGER)
36	snp_mart_44	SNP
37	vega_mart_44	Vega
38	compara_mart_homology_44	Compara homology
39	compara_mart_pairwise_ga_44	Compara pairwise alignments
40	ensembl_mart_43	ENSEMBL GENES 43 (SANGER)
41	snp_mart_43	SNP
42	vega_mart_43	Vega

```

43 compara_mart_homology_43 Compara homology
44 compara_mart_pairwise_ga_43 Compara pairwise alignments

```

Next we select the archive we want to use using the `useMart` function, again setting the archive attribute to `TRUE` and giving the full name of the BioMart e.g. `ensembl_mart_46`.

```
> ensembl = useMart("ensembl_mart_46", dataset = "hsapiens_gene_ensembl", archive = T
```

If you don't know the dataset you want to use could first connect to the BioMart using `useMart` and then use the `listDatasets` function on this object. After you selected the BioMart database and dataset, queries can be performed in the same way as when using the current BioMart versions.

6 Using a BioMart other than Ensembl

To demonstrate the use of the `biomaRt` package with non-Ensembl databases the next query is performed using the Wormbase BioMart (WormMart). We connect to Wormbase, select the gene dataset to use and have a look at the available attributes and filters. Then we use a list of gene names as filter and retrieve associated RNAi identifiers together with a description of the RNAi phenotype.

```

> wormbase = useMart("wormbase_current", dataset = "wormbase_gene")
> listFilters(wormbase)
> listAttributes(wormbase)
> getBM(attributes = c("name", "rnai", "rnai_phenotype", "phenotype_desc"), filters = "gene_name",
+       values = c("unc-26", "his-33"), mart = wormbase)

```

	name	rnai	rnai_phenotype	phenotype_desc
1	his-33	WBRNAi00000104	Emb Nmo	embryonic lethal Nuclear morphology alteration in early embryo
2	his-33	WBRNAi00012233	WT	wild type morphology
3	his-33	WBRNAi00024356	Ste	sterile
4	his-33	WBRNAi00025036	Emb	embryonic lethal
5	his-33	WBRNAi00025128	Emb	embryonic lethal
6	his-33	WBRNAi00025393	Emb	embryonic lethal
7	his-33	WBRNAi00025515	Emb Lva Unc	embryonic lethal larval arrest uncoordinated
8	his-33	WBRNAi00025632	Gro Ste	slow growth sterile
9	his-33	WBRNAi00025686	Gro Ste	slow growth sterile
10	his-33	WBRNAi00025785	Gro Ste	slow growth sterile
11	his-33	WBRNAi00026259	Emb Gro Unc	embryonic lethal slow growth uncoordinated
12	his-33	WBRNAi00026375	Emb	embryonic lethal
13	his-33	WBRNAi00026376	Emb	embryonic lethal
14	his-33	WBRNAi00027053	Emb Unc	embryonic lethal uncoordinated
15	his-33	WBRNAi00030041	WT	wild type morphology
16	his-33	WBRNAi00031078	Emb	embryonic lethal
17	his-33	WBRNAi00032317	Emb	embryonic lethal
18	his-33	WBRNAi00032894	Emb	embryonic lethal
19	his-33	WBRNAi00033648	Emb	embryonic lethal

20	his-33	WBRNAi00035430	Emb		embryonic lethal
21	his-33	WBRNAi00035860	Egl Emb	egg laying defect	embryonic lethal
22	his-33	WBRNAi00048335	Emb	Sister Chromatid Separation abnormal (Cross-eyed)	embryonic lethal
23	his-33	WBRNAi00049266	Emb	Sister Chromatid Separation abnormal (Cross-eyed)	embryonic lethal
24	his-33	WBRNAi00053026	Emb	Sister Chromatid Separation abnormal (Cross-eyed)	embryonic lethal
25	unc-26	WBRNAi00021278	WT		wild type morphology
26	unc-26	WBRNAi00026915	WT		wild type morphology
27	unc-26	WBRNAi00026916	WT		wild type morphology
28	unc-26	WBRNAi00027544	Unc		uncoordinated
29	unc-26	WBRNAi00049565	WT		wild type morphology
30	unc-26	WBRNAi00049566	WT		wild type morphology

7 biomaRt helper functions

This section describes a set of biomaRt helper functions that can be used to export FASTA format sequences, retrieve values for certain filters and exploring the available filters and attributes in a more systematic manner.

7.1 exportFASTA

The data.frames obtained by the `getSequence` function can be exported to FASTA files using the `exportFASTA` function. One has to specify the data.frame to export and the filename using the `file` argument.

7.2 Finding out more information on filters

7.2.1 filterType

Boolean filters need a value TRUE or FALSE in biomaRt. Setting the value TRUE will include all information that fulfill the filter requirement. Setting FALSE will exclude the information that fulfills the filter requirement and will return all values that don't fulfill the filter. For most of the filters, their name indicates if the type is a boolean or not and they will usually start with "with". However this is not a rule and to make sure you got the type right you can use the function `filterType` to investigate the type of the filter you want to use.

```
> filterType("with_affy_hg_u133_plus_2", ensembl)

[1] "boolean_list"
```

7.2.2 filterOptions

Some filters have a limited set of values that can be given to them. To know which values these are one can use the `filterOptions` function to retrieve

the predetermined values of the respective filter.

```
> filterOptions("biotype", ensembl)

[1] "[IG_C_gene,IG_D_gene,IG_J_gene,IG_V_gene,miRNA,miRNA_pseudogene,misc_RNA,misc_RNA_pseudo,
```

If there are no predetermined values e.g. for the entrezgene filter, then `filterOptions` will return the type of filter it is. And most of the times the filter name or it's description will suggest what values one case use for the respective filter (e.g. entrezgene filter will work with enterzgene identifiers as values)

7.3 Attribute Pages

For large BioMart databases such as Ensembl, the number of attributes displayed by the `listAttributes` function can be very large. In BioMart databases, attributes are put together in pages, such as sequences, features, homologs for Ensembl. An overview of the attributes pages present in the respective BioMart dataset can be obtained with the `attributePages` function.

```
> pages = attributePages(ensembl)
> pages

[1] "feature_page"      "structure"          "snp"                "transcript_event"  "homologs"
```

To show us a smaller list of attributes which belong to a specific page, we can now specify this in the `listAttributes` function as follows:

```
> listAttributes(ensembl, page = "feature_page")

      name                                     descri
1      ensembl_gene_id                       Ensembl Ge
2      ensembl_transcript_id                 Ensembl Transcri
3      ensembl_peptide_id                   Ensembl Prote
4      canonical_transcript_stable_id       Canonical transcript stable
5      description                           Descri
6      chromosome_name                       Chromosome
7      start_position                       Gene Start
8      end_position                         Gene End
9      strand                               S
10     band
11     transcript_start                     Transcript Start
12     transcript_end                       Transcript End
13     external_gene_id                     Associated Gene
```

14	external_transcript_id	Associated Transcript
15	external_gene_db	Associated Gene
16	transcript_db_name	Associated Transcript
17	transcript_count	Transcript
18	percentage_gc_content	% GC content
19	gene_biotype	Gene Biotype
20	transcript_biotype	Transcript Biotype
21	source	Source
22	status	Status (transcript)
23	transcript_status	Status (transcript)
24	go_biological_process_id	GO Term Accession
25	name_1006	GO Term Name
26	definition_1006	GO Term Definition
27	go_biological_process_linkage_type	GO Term Evidence
28	go_cellular_component_id	GO Term Accession
29	go_cellular_component_dm_name_1006	GO Term Name
30	go_cellular_component_dm_definition_1006	GO Term Definition
31	go_cellular_component_linkage_type	GO Term Evidence
32	go_molecular_function_id	GO Term Accession
33	go_molecular_function_dm_name_1006	GO Term Name
34	go_molecular_function_dm_definition_1006	GO Term Definition
35	go_molecular_function_linkage_type	GO Term Evidence
36	goslim_goa_accession	GOSlim GOA Accession
37	goslim_goa_description	GOSlim GOA Description
38	clone_based_ensembl_gene_name	Clone based Ensembl gene
39	clone_based_ensembl_transcript_name	Clone based Ensembl transcript
40	clone_based_vega_gene_name	Clone based VEGA gene
41	clone_based_vega_transcript_name	Clone based VEGA transcript
42	ccds	CCDS
43	embl	EMBL (Genbank)
44	ens_hs_gene	Ensembl Human
45	entrezgene	EntrezGene
46	ottd	VEGA transcript ID(s) (OTTT)
47	shares_cds_with_ens	Ensembl transcript (where OTTT shares CDS with)
48	shares_cds_with_ottd	HAVANA transcript (where ENST shares CDS with)
49	shares_cds_and_utr_with_ottd	HAVANA transcript (where ENST identical to)
50	hgnc_id	HGNC ID
51	hgnc_symbol	HGNC symbol
52	hgnc_automatic_gene_name	HGNC automatic gene
53	hgnc_curated_gene_name	HGNC curated gene
54	hgnc_automatic_transcript_name	HGNC automatic transcript
55	hgnc_curated_transcript_name	HGNC curated transcript
56	ipi	IPi
57	merops	MERO
58	imgt_gene_db	IMGT Gene

59	imgt_ligm_db	IMGT/LI
60	mim_morbid_accession	MIM Morbid Acce
61	mim_morbid_description	MIM Morbid Descri
62	mim_gene_accession	MIM Gene Acce
63	mim_gene_description	MIM Gene Descri
64	mirbase_accession	miRBase Accessi
65	mirbase_id	miRBase
66	pdb	P
67	protein_id	Prote
68	refseq_dna	RefSeq D
69	refseq_dna_predicted	RefSeq Predicted D
70	refseq_peptide	RefSeq Prote
71	refseq_peptide_predicted	RefSeq Predicted Prote
72	refseq_genomic	RefSeq Genomic
73	rfam	Rf
74	unigene	Unigene
75	uniprot_sptrembl	UniProt/TrEMBL Acce
76	uniprot_swissprot	UniProt/SwissPr
77	uniprot_swissprot_accession	UniProt/SwissProt Acce
78	pubmed	Pubm
79	wikigene_name	WikiGene
80	wikigene_description	WikiGene descri
81	hpa	Human Protein Atlas Antib
82	dbass3_id	Database of Aberrant 3' Splice Sites (DBASS3
83	dbass3_name	DBASS3 Gene
84	dbass5_id	Database of Aberrant 5' Splice Sites (DBASS5
85	dbass5_name	DBASS5 Gene
86	affy_hc_g110	Affy HC
87	affy_hg_focus	Affy HG
88	affy_hg_u133_plus_2	Affy HG U133-P
89	affy_hg_u133a_2	Affy HG U1
90	affy_hg_u133a	Affy HG
91	affy_hg_u133b	Affy HG
92	affy_hg_u95av2	Affy HG U
93	affy_hg_u95b	Affy HG
94	affy_hg_u95c	Affy HG
95	affy_hg_u95d	Affy HG
96	affy_hg_u95e	Affy HG
97	affy_hg_u95a	Affy HG
98	affy_hugene1	Affy HuGe
99	affy_huex_1_0_st_v2	Affy
100	affy_hugene_1_0_st_v1	Affy H
101	affy_u133_x3p	Affy U13
102	agilent_cgh_44b	Agilent CG
103	agilent_wholegenome	Agilent WholeG

104	codelink	Codelink
105	illumina_humanwg_6_v1	Illumina HumanWG
106	illumina_humanwg_6_v2	Illumina HumanWG
107	illumina_humanwg_6_v3	Illumina HumanWG
108	phalanx_onearray	Phalanx One
109	anatomical_system	Anatomical System (egene)
110	development_stage	Development Stage (egene)
111	cell_type	Cell Type (egene)
112	pathology	Pathology (egene)
113	anatomical_system_gnf	Anatomical System
114	development_stage_gnf	Development Stage
115	cell_type_gnf	Cell Type
116	pathology_gnf	Pathology
117	family_description	Ensembl Family Descri
118	family	Ensembl Protein Family
119	superfamily	Superfami
120	smart	SMA
121	profile	PROFI
122	prosite	PROSI
123	prints	PRIN
124	pfam	PF
125	interpro	Interp
126	interpro_short_description	Interpro Short Descri
127	interpro_description	Interpro Descri
128	transmembrane_domain	Transmembrane d
129	signal_domain	Signal d
130	ncoils	N

We now get a short list of attributes related to the region where the genes are located.

8 Local BioMart databases

The biomaRt package can be used with a local install of a public BioMart database or a locally developed BioMart database and web service. In order for biomaRt to recognize the database as a BioMart, make sure that the local database you create has a name conform with

`database_mart_version`

where database is the name of the database and version is a version number. No more underscores than the ones showed should be present in this name. A possible name is for example

```
ensemblLocal_mart_46
```

8.1 Minimum requirements for local database installation

More information on installing a local copy of a BioMart database or develop your own BioMart database and webservice can be found on <http://www.biomart.org> Once the local database is installed you can use biomaRt on this database by:

```
listMarts(host="www.myLocalHost.org", path="/myPathToWebservice/martservice")
mart=useMart("nameOfMyMart",dataset="nameOfMyDataset",host="www.myLocalHost.org", path="/myPathToWebservice/martser
```

For more information on how to install a public BioMart database see: <http://www.biomart.org/install.html> and follow link databases.

9 Session Info

```
> sessionInfo()
```

```
R version 2.10.0 (2009-10-26)
i386-pc-mingw32
```

```
locale:
```

```
[1] LC_COLLATE=English_United States.1252  LC_CTYPE=English_United States.1252  LC_
[4] LC_NUMERIC=C                           LC_TIME=English_United States.1252
```

```
attached base packages:
```

```
[1] tools      stats      graphics  grDevices  utils      datasets  methods   base
```

```
other attached packages:
```

```
[1] biomaRt_2.2.0
```

```
loaded via a namespace (and not attached):
```

```
[1] Rcurl_1.2-1 XML_2.6-0
```

```
> warnings()
```

```
NULL
```