

Using the RCircos Package

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1 Introduction

The RCircos package provides a set of graphic functions which implement basic Circos 2D track plot [1] for visualizing similarities and differences of genome structure and positional relationships between genomic intervals. The package is implemented with R graphics package that comes with R base installation and aimed to reduce the complexity of usage and increase the flexibility in integrating into other R pipelines of genomic data processing.

Currently, following graphic functions are provided:

- Chromosome ideogram plots for human, mouse, and rat
- Data plots include:
 - heatmap
 - histogram
 - lines
 - scatterplot
 - tiles
- Plot items for further decoration include:
 - connectors
 - links (lines and ribbons)
 - text (gene) labels

After successful installation of RCircos, one needs to load the library to get started using it:

```
> library(RCircos)
```

2 Input Data Format

RCircos takes the input data in the form of a data frame that could be an object returned from `read.table()` or generated with other pipelines in the current R session. The first three columns of the data frame, except for input to the link plot, must be genomic position information in the order of chromosome names, chromosome start, and chromosome end positions.

```
> data(RCircos.Histogram.Data)
> head(RCircos.Histogram.Data)
```

	Chromosome	chromStart	chromEnd	Data
1	chr1	45000000	49999999	0.070859
2	chr1	55000000	59999999	0.300460
3	chr1	60000000	64999999	0.125421
4	chr1	70000000	74999999	0.158156
5	chr1	75000000	79999999	0.163540
6	chr1	80000000	84999999	0.342921

For gene labels and heatmap plots, the gene/probe names must be provided in the fourth column. For other plots, this column could be optional.

```
> data(RCircos.Heatmap.Data)
> head(RCircos.Heatmap.Data)
```

	Chromosome	chromStart	chromEnd	GeneName	X786.0	A498	A549.ATCC	ACHN
1	chr1	934341	935552	HES4	6.75781	7.38773	6.47890	6.05517
2	chr1	948846	949919	ISG15	7.56297	10.49590	5.89893	7.58095
3	chr1	1138887	1142089	TNFRSF18	4.69775	4.55593	4.38970	4.50064
4	chr1	1270657	1284492	DVL1	7.76886	7.52194	6.87125	7.03517
5	chr1	1288070	1293915	MXRA8	4.49805	4.72032	4.62207	4.58575
6	chr1	1592938	1624243	SLC35E2B	8.73104	8.10229	8.36599	9.04116

	BT.549	CAKI.1
1	8.85062	7.00307
2	12.08470	7.81459
3	4.47525	4.47721
4	7.65386	7.69733
5	5.66389	4.93499
6	9.24175	9.89727

Different from other plot data, the input data for link line plot has only paired genomic position information for each row in the order of chromosome name A, chromStart A, chromEnd A, chromosome name B, chromStart B, and chromEnd B.

```
> data(RCircos.Link.Data)
> head(RCircos.Link.Data)
```

	Chromosome	chromStart	chromEnd	Chromosome.1	chromStart.1	chromEnd.1
1	chr1	8284703	8285399	chr1	8285752	8286389
2	chr1	85980143	85980624	chr7	123161313	123161687
3	chr1	118069850	118070319	chr1	118070329	118070689
4	chr1	167077258	167077658	chr1	169764630	169764965
5	chr1	171671272	171671550	chr1	179790879	179791292
6	chr1	174333479	174333875	chr6	101861516	101861840

Note: RCircos will convert the input data to RCircos plot data but it does not provide functionality for general data processing. If the data frame does not have genomic position information, you have to add the information to the data frame before passing it to RCircos functions. Sample datasets are included in the package for demo purpose and they could be easily explored with data() method.

Starting from version 1.1.2, user can append to input data a column of plot color names with header of "PlotColor" to control the colors for each data point except of heatmap plot.

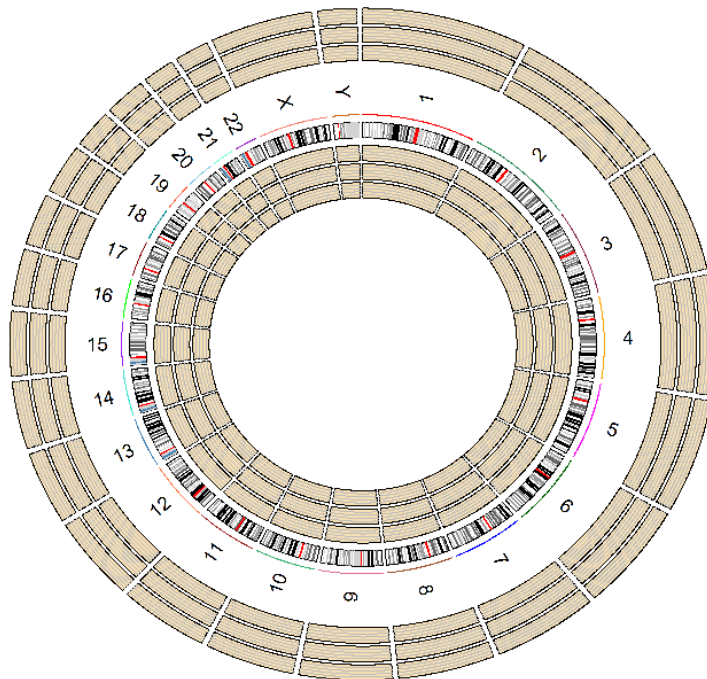
3 Plot Track Layout

RCircos follows the same algorithm of Circos plot and arranges data plots in tracks. A track could be placed either inside or outside of chromosome ideogram

and the detailed position for a track could be easily manipulated by changing of the track width and track numbers.

The figure below shows a human chromosome ideogram plus three empty tracks arranged in both inside and outside of chromosome ideogram.

R Circos Layout Demo



4 Getting Started: Initialize RCircos core components first

4.1 Initialize RCircos core components

The first step of making RCircos plot is to initialize RCircos core components. To setup RCircos core components, user needs load the chromosome ideogram data into current R session. The RCircos package have three build-in datasets for human, mouse, and rat chromosome ideograms which can be loaded with `data()` command. Ideogram data in text files with same format can also be

loaded with read.table() function in R.

```
> data(UCSC.HG19.Human.CytoBandIdeogram);  
> head(UCSC.HG19.Human.CytoBandIdeogram);
```

	Chromosome	ChromStart	ChromEnd	Band	Stain
1	chr1	0	2300000	p36.33	gneg
2	chr1	2300000	5400000	p36.32	gpos25
3	chr1	5400000	7200000	p36.31	gneg
4	chr1	7200000	9200000	p36.23	gpos25
5	chr1	9200000	12700000	p36.22	gneg
6	chr1	12700000	16200000	p36.21	gpos50

```
> data(UCSC.Mouse.GRCm38.CytoBandIdeogram);  
> head(UCSC.Mouse.GRCm38.CytoBandIdeogram);
```

	Chromosome	ChromStart	ChromEnd	Band	Stain
1	chr1	0	8840440	qA1	gpos100
2	chr1	8840440	12278390	qA2	gneg
3	chr1	12278390	20136559	qA3	gpos33
4	chr1	20136559	22101102	qA4	gneg
5	chr1	22101102	30941543	qA5	gpos100
6	chr1	30941543	43219933	qB	gneg

```
> data(UCSC.Baylor.3.4.Rat.cytoBandIdeogram);  
> head(UCSC.Baylor.3.4.Rat.cytoBandIdeogram);
```

	Chromosome	ChromStart	ChromEnd	Band	Stain
1	chr1	0	10142096	p13	gneg
2	chr1	10142096	24272657	p12	gvar
3	chr1	24272657	38517175	p11	gneg
4	chr1	38517175	48659271	q11	gpos
5	chr1	48659271	69741157	q12	gneg
6	chr1	69741157	90025350	q21	gpos

After the chromosome ideogram data is loaded, RCircos core components can be initialized with function of RCircos.Set.Core.Components(). This function needs four arguments:

cytoinfo the chromosome ideogram data loaded

chr.exclude chromosomes should be excluded from ideogram, e.g., chr.exclude <- c("chrX", "chrY");. If it is set to NULL, no chromosome will be excluded.

tracks.inside how many tracks will be plotted inside chromosome ideogram

tracks.outside how many data tracks will be plotted outside chromosome ideogram

Following code initialize RCircos core components with all human chromosome ideogram and 10 data track space inside of chromosome ideogram.

```
> chr.exclude <- NULL;
> cyto.info <- UCSC.HG19.Human.CytoBandIdeogram;
> tracks.inside <- 10;
> tracks.outside <- 0;
> RCircos.Set.Core.Components(cyto.info, chr.exclude,
+   tracks.inside, tracks.outside);
```

RCircos use three core components to perform data transformation and data plot:

RCircos cytoband data RCircos cytoband data is derived from the input chromosome ideogram data. Except of the chromosome name, start and end positions, band name and stain intensity for each band, chromosome highlight colors, band colors, band length in base pairs and chromosome units as well as the relative location on the circular layout are also included. These data are used to calculate the plot location of each genomic data.

RCircos plot positions RCircos plot positions are x and y coordinates for a circular line of radius 1.0 and the total number of points for the circular line are decided by the total number of chromosome units. One chromosome units is a plot point which covers a defined number of base pairs and total units for chromosome ideogram include units of each band plus chromosome padding area, both of them are defined in the list of plot parameters.

RCircos plot parameters RCircos plot parameters are only one core components open to users. With the get and reset methods, users can modify the parameters for updating other two core components. Following are RCircos plot parameters and their default values:

base.per.unit Number of base pairs a chromosome unit (a plot point) will cover, default: 30000

chrom.paddings Width of padding between two chromosomes in chromosome unit, default: 300 (Note: chrom.paddings is binded to base.per.unit. It will be automatically updated if the base.per.unit is changed, unless be set to zero).

tracks.inside Total number of data tracks inside of chromosome ideogram. Read-only.

tracks.outside Total number of data tracks outside of chromosome ideogram. Read-only.

radiu.len The radius of a circular line which serves as baseline for calculation of plot items, default: 1

plot.radius Radius of plot area,default: 1.5

chr.ideo.pos Radius of chromosome ideogram position, default: 1.1

highlight.pos Radius of chromosome ideogram highlights, default: 1.25

chr.name.po Radius of chromosome name position, default: 1.4

track.in.start Radius of start position of the first track inside of chromosome idogram, default: 1.05

track.out.start Radius of start position of the first track outside of chromosome idogram, default: 1.6

chrom.width Width of chromosomes of the ideogram, default: 0.1

track.padding Width of padding between two plot tracks, default: 0.02

track.height Height of data plot track, default: 0.1 (Note: Parameters above are all relative to the radius.len and will be updated automatically if new radiu.len is reset.)

hist.width Width of histogram column in chromosome unit, default: 100

heatmap.width Width of heatmap cells in chromosome unit, default: 100

text.size Character size (same as cex in R graphics package) for text plot, default: 0.4

char.width Width of a charater on RCircos plot, default 500 (chromosome unit)

highlight.width Line type (same as lty in R graphics package) for chromosome highlight, default: 2

point.size Point size (same as cex in R graphics package) for scatter plot, default: 1

Bezier.point Total number of points for a link(Bezier) line default: 1000

max.layers Maximum number of layers for tile plot, default: 5

sub.tracks Number of sub tracks in a data track, default: 5

text.color Color for text plot, default: black

hist.color Color for histogram plot, default: red

line.color Color for line plot, default: black

scatter.color Color for scatter plot, default: black

tile.color Color for tile plot, default: black

track.background Color of track background, default: wheat

grid.line.color Color for track grids, default: gray

heatmap.color Color scales for heatmap plot, default: BlueWhiteRed

point.type Point type (same as pch in R graphics package) for scatter plot, default: "."

The core components are stored in RCircos session and each component is supplied with one Get method for advanced usage. In addition, simply call the function `RCircos.List.Parameters()` will list all current plot parameters.

```
> rcircos.params <- RCircos.Get.Plot.Parameters();
> rcircos.cyto <- RCircos.Get.Plot.Ideogram();
> rcircos.position <- RCircos.Get.Plot.Positions();

> RCircos.List.Plot.Parameters()
```

4.2 Modifying RCircos core components

Among the three RCircos core components, RCircos cytoband data and RCircos plot positions are calculated based on plot parameter setting. Users can modify RCircos core components by changing plot parameters. Once the plot parameter(s) is changed, call and pass the new parameters to the function of `RCircos.Reset.Plot.Parameters()`, other two components will be checked for update.

```
> rcircos.params <- RCircos.Get.Plot.Parameters();
> rcircos.params$base.per.unit <- 3000;
> RCircos.Reset.Plot.Parameters(rcircos.params);

> RCircos.List.Plot.Parameters();
```

5 Making a Plot with RCircos

Plotting with RCircos is a stepwise process. First, an initialization step is needed. Then, tracks and other aspects of the plot are added sequentially. The result is available after the plot has been entirely constructed. The next subsections walk through the process in detail.

5.1 Initialize Graphic Device

RCircos provides a set of graphic plot functions but does not handle graphic devices. To make RCircos plots, a graphic device has to be opened first. Currently, RCircos works with files supported by R graphics package such as tiff, png, pdf images as well as GUI windows. For example, to make a pdf file with RCircos plot image:

```
> out.file <- "RCircosDemoHumanGenome.pdf";
> pdf(file=out.file, height=8, width=8, compress=TRUE);
> RCircos.Set.Plot.Area();
```

Note: `RCircos.Set.Plot.Area()` will setup plot area base on total number of tracks inside and outside of chromosome ideogram. User can also setup plot area by summit the R plot commands for user defined plot area, for example:


```
> par(mai=c(0.25, 0.25, 0.25, 0.25));
> plot.new();
> plot.window(c(-2.5,2.5), c(-2.5, 2.5));
```

Note: After everything is done, the graphic device needs to be closed with `dev.off()`.

5.2 Plot Chromosome Ideogram

For RCircos plot, a common first step is to draw chromosome ideograms and label chromosomes with names and highlights. After the RCircos core components were initialized and graphic device was open, simply call the function of `RCircos.Chromosome.Ideogram.Plot()` will add the chromosome ideogram to the current plot.

```
> RCircos.Chromosome.Ideogram.Plot();
```

5.3 Gene Labels and connectors on RCircos Plot

Due to the resolution issues, only limited number of gene names can be labeled. For best visualization, `cex` should be no less than 0.4 when draw gene labels. When `cex` is set to 0.4, width of character will be 5000 chromosome units when each unit covers 3000 base pairs. If the gene name list supplied is too long, it will be truncated to fit the chromosome length. Also the long gene name will span more than one track so one or more tracks may be needed to skip for next track.

Connectors are used to mark a genomic position with their names or variant status. Currently, RCircos only provide connector plot between genes and their genomic positions. The following code draw connectors on the first track inside chromosome ideogram and plot gene names on the next track.

```
> data(RCircos.Gene.Label.Data);
> name.col <- 4;
> side <- "in";
> track.num <- 1;
> RCircos.Gene.Connector.Plot(RCircos.Gene.Label.Data,
+   track.num, side);
> track.num <- 2;
> RCircos.Gene.Name.Plot(RCircos.Gene.Label.Data,
+   name.col, track.num, side);
```

5.4 Heatmap, Histogram, Line, Scatter, and Tile Plot

Heatmap, histogram, line, scatter, and tile plot with RCircos require that the first three columns of input data are genomic position information in the order of chromosome name, start, and end position. RCircos provides one function for each type of plots and each function will draw one data track. User can simply

call each function with appropriate arguments such as plot location (which track and which side of chromosome ideogram). No more data processing needed.

The code below will draw data tracks of heatmap, scatter, line, histogram, and tile plots.

```
> data(RCircos.Heatmap.Data);
> data.col <- 6;
> track.num <- 5;
> side <- "in";
> RCircos.Heatmap.Plot(RCircos.Heatmap.Data, data.col,
+   track.num, side);

> data(RCircos.Scatter.Data);
> data.col <- 5;
> track.num <- 6;
> side <- "in";
> by.fold <- 1;
> RCircos.Scatter.Plot(RCircos.Scatter.Data, data.col,
+   track.num, side, by.fold);

> data(RCircos.Line.Data);
> data.col <- 5;
> track.num <- 7;
> side <- "in";
> RCircos.Line.Plot(RCircos.Line.Data, data.col,
+   track.num, side);

> data(RCircos.Histogram.Data);
> data.col <- 4;
> track.num <- 8;
> side <- "in";
> RCircos.Histogram.Plot(RCircos.Histogram.Data,
+   data.col, track.num, side);

> data(RCircos.Tile.Data);
> track.num <- 9;
> side <- "in";
> RCircos.Tile.Plot(RCircos.Tile.Data, track.num, side);
```

5.5 Links: A Special Plot

Links presents relationship of two genomic positions and it is always the last track inside chromosome ideogram. Different from other data plots, input data for links plot is a data frame with paired genomic positions in the order of chromosome, start, and end position for each one genomic position. RCircos supports two types of link plot: lines and ribbons. Link lines are used for presenting relationship of two small genomic regions and ribbons are plotted for

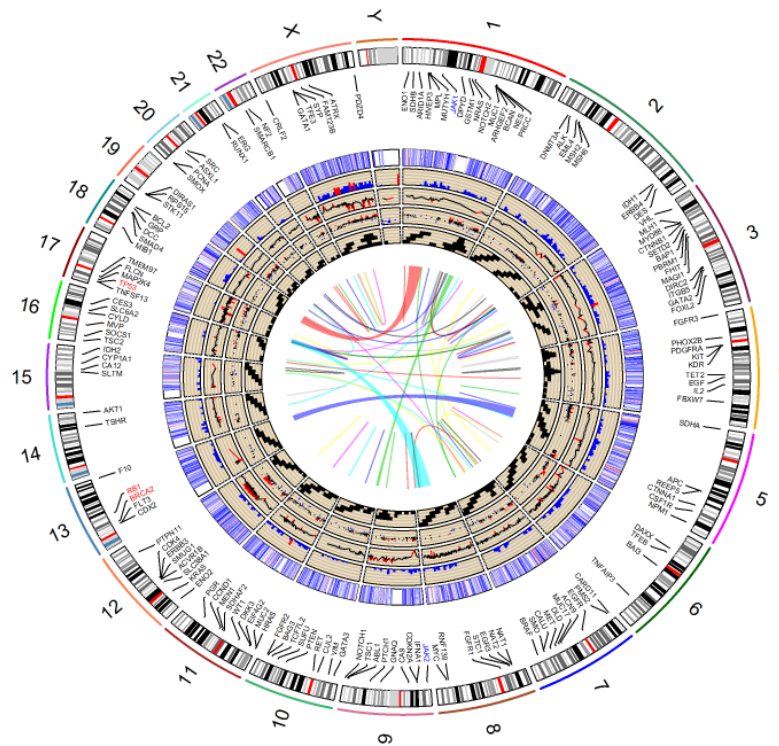
bigger genomic regions. Colors for links between chromosomes or same chromosomes could be modified by defining `by.chromosome=TRUE` (or `FALSE`).

Following code draw link lines and ribbons in the center of plot area.

```
> data(RCircos.Link.Data);  
> track.num <- 11;  
> RCircos.Link.Plot(RCircos.Link.Data, track.num, TRUE);  
> data(RCircos.Ribbon.Data);  
> RCircos.Ribbon.Plot(ribbon.data=RCircos.Ribbon.Data,  
+   track.num=11, by.chromosome=FALSE, twist=FALSE);  
> dev.off();
```

Run all code above will generate an image like below.

RCircos Demo with Human Genome



6 More Information

Several demo samples are included in the package. Simply run following demos to see how the RCircos works for simple and complex RCircos plot.

```
> library(RCircos);
> demo("RCircos.Demo.Human");
> demo("RCircos.Demo.Mouse.And.Rat");
```

7 sessionInfo

```
> sessionInfo()

R version 3.5.1 (2018-07-02)
Platform: x86_64-pc-linux-gnu (64-bit)
Running under: CentOS Linux 7 (Core)

Matrix products: default
BLAS: /gpfs/gsf8/users/hzhang/WorkBin/R-3.5.1/lib64/R/lib/libRblas.so
LAPACK: /gpfs/gsf8/users/hzhang/WorkBin/R-3.5.1/lib64/R/lib/libRlapack.so

locale:
 [1] LC_CTYPE=en_US.UTF-8      LC_NUMERIC=C
 [3] LC_TIME=en_US.UTF-8      LC_COLLATE=C
 [5] LC_MONETARY=en_US.UTF-8  LC_MESSAGES=en_US.UTF-8
 [7] LC_PAPER=en_US.UTF-8     LC_NAME=C
 [9] LC_ADDRESS=C             LC_TELEPHONE=C
[11] LC_MEASUREMENT=en_US.UTF-8 LC_IDENTIFICATION=C

attached base packages:
[1] stats      graphics  grDevices  utils      datasets  methods    base

other attached packages:
[1] RCircos_1.2.1

loaded via a namespace (and not attached):
[1] compiler_3.5.1 tools_3.5.1
```

References

- [1] Krzywinski, Martin I and Schein, Jacqueline E and Birol, Inanc and Connors, Joseph and Gascoyne, Randy and Horsman, Doug and Jones, Steven J and Marra, Marco A. Circos: An information aesthetic for comparative genomics. *Genome Research*, 2009.