User Manual of WebGestalt 2019

April 28th, 2019

The WEB-based GEne SeT AnaLysis Toolkit (WebGestalt) is a suite of tools for functional enrichment analysis in various biological contexts. The original version of WebGestalt was described in the paper “WebGestalt: an integrated system for exploring gene sets in various biological contexts” (Nucleic Acids Res. 2005 Jul 1;33(Web Server issue): W741-8), followed by two updates: WebGestalt 2013, described in the paper “WEB-based GEne SeT AnaLysis Toolkit (WebGestalt): update 2013” (Nucleic Acids Res. 2013 Jul 1;41(Web Server issue): W77-83) and WebGestalt 2017 described in “WebGestalt 2017: a more comprehensive, powerful, flexible and interactive gene set enrichment analysis toolkit” (Nucleic Acids Res. 2017 Jul 3;45(Web Server issue): W130-137). WebGestalt has been visited by 26,000 unique users on average per year from 144 countries and territories according to Google Analytics. The publications have also been cited in more than 2,500 scientific according to Google Scholar.

For WebGestalt 2019, the following major improvements are introduced compared to the WebGestalt 2017 version:

- The new version significantly increases the number of functional categories from 134496 to 152819, which includes the protein complex databases CORUM and a cancer-related subset of WikiPathway.
- Notably, annotations of kinases and their targeting phosphorylation sites are collected from RegPhos database to uniquely enable enrichment analysis of phosphorylation data from proteomics experiments.
- The new version increases the number of gene identifiers from 300 to 342, mostly from microarray platforms.
- The HTML report has been redesigned with emphasis on improving usability and visualizations that could potentially turn into publication-ready figures.
  - For ORA and GSEA, the report is divided into three main sections, with folded summaries, tabs of visualizations, and detailed information of the enriched gene set currently in view.
  - Plots can all be saved as high-resolution PNG files or SVG vector format.
  - Besides summarized in a plain table, enrichment results are also visualized in bar chart and volcano plot. If the gene sets have hierarchical structure, like GO terms, a DAG (directed acyclic graph) will also be shown. Clicking on the gene set will pull up the detailed information of the corresponding gene set.
  - The bar chart sorts result by enrichment ratio (for ORA) or NES (GSEA). Gene sets with FDR < 0.05 are colored in darker shade. GSEA results may also have results that are negatively enriched.
  - The volcano plot includes scores for all the functional categories in the search database. And the size and color of the dots scale with the size of the gene sets. The plot can be zoomed and panned. Labels can be
changed between set ID and name, and their positions can be manually adjusted by dragging to avoid overlap.

- The DAG now occupies the full width of the page, which should be easier to explore in the new vertical layout compared to the 2017 version.
- The section of detailed information includes statistics in highlight, the table of overlap or leading-edge genes. Venn diagram for ORA or GSEA enrichment plot is also displayed.
- Two methods (affinity propagation and weighted set cover) to reduce redundancy of the gene sets in the enrichment result are run to obtain subsets that could be easier to view and focus on when the number of results is overwhelming.
- The report of NTA method has also been redesigned similarly, showing interlinked network, DAG of enriched GO categories and current gene table.

- The R interface of WebGestalt has been updated to work with the new version and published on CRAN (version 0.3.0). It returns a data frame of the enrichment result and could also generate the same HTML report as on the server as well. This allows integration into other computation pipelines and running large batch of jobs locally.
- The WebGestalt website now also accepts data through a web API, either directly submitting a job or linking from a third-party website with part of data (such as gene list) loaded in the form and letting users choose the rest parameters.

![Figure 1. Summary of visualization improvement compared to the 2017 version.](image)
At the top of the WebGestalt interface (blue box in Figure 1), users can find the link about the sample run, external examples, this manual, citation information and user forum. Users are encouraged to post questions or problems they encounter in the user forum. Clicking the “ORA Sample Run”, “GSEA Sample Run”, “NTA Sample run” or “Phosphosite Sample Run” can automatically fill out all parameters in the interface related to each method or data type for a test run. Support for phosphosite data is newly introduced in the 2019 version. “External Examples” link provides some examples that can guide users to prepare their own data for analysis. The right part of the page also includes the introduction of the WebGestalt 2019, Data sources and News. The following sections will introduce the detailed information about the input parameters and the output report of WebGestalt.

WEB-based GEne SeT AnaLysis Toolkit
Translating gene lists into biological insights...

Figure 2. WebGestalt submission interface
1. Select an interesting organism

A user needs to select an organism of interest from the drop-down menu that includes 12 organisms plus an “others” option. We will introduce “others” in the “Select a functional database” section.

Figure 3. Selection of an interesting organism.
2. Select an interesting method

A user needs to select a method of interest from the dropdown. Different methods have different parameter inputs.

Figure 4. Selection of an interesting method
3. Select a functional database

3.1 For “others” organism

If a user selects “others” from the “Select Organism of Interest” menu, the user can analyze any kind of data not currently provided by WebGestalt. The user needs to upload the functional database, genes of interest, and reference genes (for the ORA method). Because WebGestalt will not perform any ID mapping for the uploaded data (all ID type related options are disabled (blue box in Figure 5)), the user needs to make sure that the ID types in all uploaded data are the same.

The uploaded functional database file should have an extension of “.gmt”. As shown in Table 1, the first column of the file is the gene set ID, the second column is the external link to the gene set and other columns are the gene IDs annotated to this gene set. The file should be tab-delimited. If each gene set ID also has a description (e.g. the name of the gene set ID), the user can also upload a “des” file (this is optional). As shown in Table 2, the first column is the gene set ID which should be identical to the ID in the gmt file, and the second column is the description for each gene set. All columns should be separated by tab.

Figure 5. The “others” option for “Select Organism of Interest”.

WEB-based GEnE SeT AnaLysis Toolkit

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Introduction

WebGestalt 2019 has been officially released with updated data. The 2017 version can be accessed through the link.

WebGestalt (WEB-based Gene SeT Analysys Toolkit) is a functional enrichment analysis web tool, which has on average 20,000 unique users from 144 countries and territories per year according to Google Analytics. The tool releases yearly, with WebGestalt 2017 in February 2018 and currently has more than 2,350 scientific papers according to Google Scholar.

WebGestalt 2014 significantly improved the output report with emphasis on providing user-friendly interfaces which could directly translate into publication-ready figures. The R package Bioconductor has been updated to work with the new version, which provides an interface to integrate into other pipelines or run batch jobs locally. We also support publication in the form of a web application, and include an API to perform enrichment analysis. WebGestalt supports three well-established and complementary methods for enrichment analysis, including Over-Representation Analysis (ORA), Gene Set Enrichment analysis (GSEA), and Network Topology-based Analysis (NTA).

Data Source

News
### Table 1. An example of the “gmt” file

<table>
<thead>
<tr>
<th>Geneset</th>
<th>URL</th>
<th>Gene1</th>
<th>Gene2</th>
<th>Gene3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geneset1</td>
<td><a href="http://www.webgestalt.org/Geneset1">http://www.webgestalt.org/Geneset1</a></td>
<td>Gene11</td>
<td>Gene12</td>
<td>Gene13</td>
</tr>
<tr>
<td>Geneset2</td>
<td><a href="http://www.webgestalt.org/Geneset2">http://www.webgestalt.org/Geneset2</a></td>
<td>Gene21</td>
<td>Gene22</td>
<td></td>
</tr>
<tr>
<td>Geneset3</td>
<td><a href="http://www.webgestalt.org/Geneset3">http://www.webgestalt.org/Geneset3</a></td>
<td>Gene31</td>
<td>Gene32</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. An example of the “des” file

<table>
<thead>
<tr>
<th>Geneset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geneset1</td>
<td>The description of Geneset1</td>
</tr>
<tr>
<td>Geneset2</td>
<td>The description of Geneset2</td>
</tr>
<tr>
<td>Geneset3</td>
<td>The description of Geneset3</td>
</tr>
</tbody>
</table>
3.2 For supported organisms

If the user selects one of the 12 organisms, there is a dropdown menu to show eight categories: geneontology, pathway, network, phenotype, disease, drug, chromosomal location and “others” option. Except “others”, after selecting one of the other seven classes, the detailed database names in the class will be shown in another dropdown menu (see Figure 6). For gene ontology categories, we used an algorithm to remove redundant terms and create three more databases only containing non-redundant terms. Due to running time consideration, the user can only use the non-redundant version for the GSEA GO enrichment analysis. Full set of gene ontology is available in the WebGestaltR package.

Figure 6. Selection of the functional database
WebGestalt now supports multiple databases for ORA. User could click the plus button in Figure 6a to add more databases. The built-in databases and uploaded custom database will be combined on the fly for enrichment analysis. **Multiple database support is available for GSEA in WebGestaltR.**

If the user selects the “others” category, the user can upload a functional database not included in WebGestalt (see blue box in Figure 7). Because the user has selected one of 12 organisms instead of the “others” organism, WebGestalt will perform the ID mapping for all uploaded files (all ID type related options are still active (red box in Figure 7)), which means it is not necessary to upload the files with the same ID types. Thus, the user also needs to select the ID type of the uploaded functional database file.
Figure 7. The “others” class selection of functional database

For the NTA method, users only need to select the networks from the dropdown menu.
4. Upload gene list

After selecting or uploading the functional database, the user needs to upload or paste a gene list. As shown in Figure 8, the user should first select the ID type of the gene list from the dropdown menu (red box). Then, if the user selects the “ORA” method, the user can upload a “txt” file with only one column or paste a gene list to the text box (blue box in Figure 8). If the user selects the “GSEA” method, the user should upload a “rnk” file with two columns: gene IDs and the scores separated by tab (see Table 3) or paste gene IDs and the scores separated by tab in the text box.

Table 3. An example of “rnk” file

<table>
<thead>
<tr>
<th>Gene1</th>
<th>1.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gene2</td>
<td>-1.1</td>
</tr>
<tr>
<td>Gene3</td>
<td>-3.3</td>
</tr>
<tr>
<td>Gene4</td>
<td>5.5</td>
</tr>
</tbody>
</table>
5. Upload the reference gene list

For the “ORA” method, the user needs to select a reference gene list from a dropdown menu (see Figure 9) for example genome or many microarray platforms or select ID type and upload a custom “txt” file. The “GSEA” method does not need a reference gene list.

Figure 9. Selection of the reference gene list
6. Advanced parameters

The user can also set some advanced parameters for different methods. The first panel in Figure 10 shows the advanced parameters for the ORA and GSEA methods.

- Setting the “Minimum Number of Genes for a Category” will remove the categories with sizes less than this number. The category size is calculated based on the number of overlapping genes between the annotated genes in the category and the reference gene list for the “ORA” method (or ranked gene list for the “GSEA” method).
- Setting the “Maximum Number of Genes for a Category” will remove the categories with sizes greater than this number.
- “Multiple Test Adjustment” will set the FDR method from “BH”, “BY”, “bonferroni”, “Holm” and “Hommel”. This option is only for the “ORA” method.
- The “Significance Level” parameter has two options. “FDR” means the enriched categories will be identified based on the FDR threshold and “TOP” means the categories will be first ranked based on the FDR and then the top N most significant categories will be selected. For the GSEA method, the “TOP” method will select the top N most significant categories from positive and negative related categories separately.
- “Number of Permutations” and “Collapse Method” parameters are just for the “GSEA” method. These indicate how many permutations to perform and which method will be used for collapsing any duplicate IDs.
- “Number of categories expected from set cover” indicates the number of the expected reduced sets of the weighted set cover algorithm for redundancy reduction in the report. The algorithm stops either covering all the genes or reaching the number.
- “Number of categories visualized in the report” represents how many significant categories will be shown in the report. All the categories passing the significance level will be obtained in the download result. For the GSEA method, this number represents how many positive related categories or how many negative related categories will be visualized. If this number is 40, the report can at most contain 80 significant categories.
- If “Color in DAG” is continuous, the categories of the DAG structure in the output report will be colored in gradient based on the FDR. Otherwise, WebGestalt will use steel blue color for ORA method or steel blue and dark orange color for GSEA method to color the significant categories.
Figure 10 also shows the advanced parameters for the two NTA methods.

- NTA includes two network construction method: “Network Retrieval & Prioritization” and “Network Expansion”. “Network Retrieval & Prioritization” first uses random walk analysis to calculate random walk probability for the input seeds, then identifies the relationships among the seeds in the selected network and returns a retrieval sub-network. The seeds with the top random walk probability are highlighted in the sub-network. “Network Expansion” first uses random walk analysis to rank all genes in the selected network based on their network proximity to the input seeds and then returns an expanded sub-network in which nodes are the input seeds and their top ranking neighbors and edges represent their relationships.
• For “Network Retrieval & Prioritization”, users need to set how many seeds will be highlighted in the retrieved sub-network. For “Network Expansion” method, users need to set how many top-ranking neighbors will be included in the expanded sub-network and also to set which type of genes will be highlighted in the sub-network (seeds or neighbors).

• These two methods finally will perform the enrichment analysis for the identified sub-networks based on the GO Biology Process ontology. Thus, users need to select the criteria for identifying the significant categories.
if the ID type of the uploaded data is from one of 12 organisms, the output report will contain two major sections: “Summary” and “Enrichment Results”. Summary includes two folded sections of job parameters used in the analysis and the GO Slim summary, which contains three bar plots illustrating the number of genes in the uploaded gene list that overlap with the annotated genes in the GO Slim terms from biological process (red bar plot), cellular component (blue bar plot) and molecular function (green bar plot) ontologies, respectively (see Figure 11). Clicking the “Result Download” link will download a zip file with the HTML report and text file of all the results.

Figure 11. GO Slim summary of input genes
7.2 Enrichment Results

7.2.1 Result visualization

To illustrate the new visualizations and features in the 2019 version, we will use the ORA sample run directly available from the homepage as an example. For this sample run, we set the FDR threshold to 0.05 and allow to visualize up to 100 enriched sets. Note the ORA sample run in the 2017 version only visualized the top 10 enriched sets.

The “Enrichment Results” section first has tabs of different visualizations of the significant enrichment result, followed by the detailed information of the current viewing gene set with scoring statistics, gene table etc. The visualizations include table summarization, bar chart and volcano plot (see Figure 12), and DAG (when applicable). Bar chart, volcano plot and redundancy reduction (red box in Figure 12, discussed in 7.3) are new components in WebGestalt 2019, and DAG is reimplemented with Cytoscape.js instead of the obsolete Flash plugin.

The table concisely summarize the enriched functional categories with their statistics. It is similar to the returned value with the WebGestaltR package. The table can be sorted by the scores and statistics by clicking on the headers (Figure 12). The number of rows per page can be adjusted (blue box in Figure 12). Clicking the gene set name will pull up the detailed information about the category in the bottom section and scroll to it.

The bar chart plots the enrichment results vertically with the bar width equal to enrichment ratio in ORA or NES in GSEA (Figure 13). If there are negatively related categories in GSEA result, the chart will go in two directions with different colors. When
the FDR for the categories is smaller than or equal to 0.05, the colors of the bar are darker, while the color for categories with FDR larger than 0.05 is in a lighter shade. This is useful when significant level is chosen as “Top”.

As for the ORA example, the bar chart can adjust its height, but it is still a very long graph (Figure 13). Another bar chart from a different GSEA run shows a two-sided bar chart (Figure 14). Right clicking on the plot will show download buttons to save it in SVG and PNG formats (Figure 14).
The **volcano plot** shows log of FDR against enrichment ratio or NES for all the categories in the search database (Figure 15). Significant categories will be near the upper corners. The size and color of the dot is proportional to the size of the category. Hovering over a dot will show some information about it and clicking on it will update the detailed information section. User can pan and zoom the plot after activating a switch button. The enriched categories are labeled, and the positions of the labels can be adjusted manually with mouse, since no perfect automatic positioning can always be achieved. The label can be changed to the gene set name and a linking line to the dot can be added with a button (Details about the customization are further discussed later in 7.2.3). User can download the plot in SVG or PNG formats after fine tuning in the bottom toolbox (blue box in Figure 15).

For the ORA sample run, all functional categories with FDR <= 0.05 are labelled, heavily overlapping with each other, and not suitable for publication.
If the functional database contains the **DAG** or tree structure, such as GO terms, the structure will be visualized in another tab (Figure 16). If the “Color in DAG” is continuous, the significant categories will be colored by gradient based on the FDR. Otherwise, the categories will be colored by steel blue. For the GSEA method, the positively related categories will be colored by blue gradient while the negatively related categories will be colored by orange gradient if the “Color in DAG” is continuous. Otherwise, the positively and negatively related categories will be colored by steel blue and dark orange, respectively. The user can pan and zoom with mouse scroll or touchpad to navigate the DAG. Right clicking on the plot shows a menu with the options to resize and save the current view to a high-resolution PNG file. Clicking on the colored nodes (significant categories) will select the category to view the detailed information.

The sample ORA run is a typical situation when many diverse GO terms are identified and make the graph very wide and difficult to browse and present. The 2019 version introduces a compact mode which minimizes styles of ancestor nodes and utilizes full browser window width compared with old version, which only used half of the window width, but may still fall short in such cases. In such cases, user could export the graph layout in Cytoscape JSON format and open it in the Cytoscape desktop version. WebGestalt 2019 also changes the implementation of DAG to Cytoscape.js library from the obsolete Cytoscape Web, removing the need of the Flash plugin. Note the sensitivity of the mouse scroll is device dependent and should be set at a default that should work well for most devices according to Cytoscape.js documentation.
7.2.2 Redundancy reduction

The redundancy reduction selection above the visualization tabs (See red box in Figure 12) give users a reduced set of results to inspect, which is especially meaningful when the database is redundant, or the number of results is overwhelming. Two methods of redundancy reduction, affinity propagation and weighted set cover are run as a post-processing step to identify the most representative sets with low redundancy for visualization (manuscript under revision).

In short, affinity propagation clusters gene sets with Jaccard index as similarity measurement and automatically identify an “exemplar” or representative for each cluster with priority for set with significant P-value. Weighted set cover finds a minimum subset of gene sets that can cover all the genes from the enriched sets, while the weight or cost of adding a set is associated with its P-value. Weighted set cover may stop early before convergence when the input parameter limiting the expected set number is reached. Details of the algorithms could be found in appendix at the end.

Selecting either method will result in a subset of categories appearing in the visualization tabs. Detailed information about the clustering can be found in the download result, such as members in the affinity propagation cluster and gene coverage of the set cover.

Here we then show the corresponding visualizations of the subset from affinity propagation for the ORA sample run results below. There are much less gene sets in the reduced result, making it more manageable. Meanwhile, important biological themes are all covered with these selected gene sets. More information about gene sets relationship in affinity propagation and gene coverage of set cover can be found in the download result.
Figure 17. Bar chart of reduced sets of the ORA sample run from affinity propagation

Figure 18. Volcano plot of reduced sets of the ORA sample run from affinity propagation
7.2.3 Volcano plot customization

Volcano plot is implemented with interactivity and customization in mind. On startup, the labels of enrich sets are positioned automatically by a force field-based algorithm. User could further adjust label position by dragging the label around with mouse. The label text can be switched between set ID or the description, which is usually more meaningful but also could be too verbose sometimes. A line linking the label and its data point could be drawn by clicking the button in the bottom toolbox. The plot can be moved and zoomed in after activating the “Pan & zoom” switch in the toolbox. After fine adjustment, the plot can be saved in SVG or PNG formats with the download button.

Figure 20 shows the label positions after manual adjustment for the affinity propagation subset of the ORA sample run. The inset compares it with the default positions from Figure 18. Figure 21 demonstrates further changing label text to gene set description, and a high-resolution plot can be downloaded and used directly for presentation or publication.
Figure 20. Manual adjustment of volcano plot label position

Figure 21. Switching label text to gene set description in volcano plot
7.3 Detailed information for individual enriched gene sets

The **detailed information** section contains scoring statistics and links to external database and downloading the gene table. The section can be updated to select category either by clicking on corresponding elements in the plots or directly typing or selecting through the select box (Blue box in Figure 22). The gene table lists the overlapping or leading edge genes with the gene symbol, name and links to NCBI and can be sorted by clicking headers. The number of rows per page can be adjusted. For ORA, there is a Venn diagram showing the overlap between the genes in the input and those in the database (Figure 23). For GSEA, it is replaced by an enrichment plot showing the rank distribution, running sum, and where its peak is (Figure 22).

![Gene set: GO:0006575 cellular modified amino acid metabolic process](image)

<table>
<thead>
<tr>
<th>User ID</th>
<th>FDR</th>
<th>P Value</th>
<th>Gene Symbol</th>
<th>Gene Name</th>
<th>Entrez Gene ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>14671</td>
<td>0.013895</td>
<td>0</td>
<td>Got7</td>
<td>glutathione S-transferase theta 1</td>
<td>14671</td>
</tr>
<tr>
<td>14651</td>
<td>0.061135</td>
<td>0.00068991</td>
<td>Glxyd</td>
<td>hydroxyacyl glutathione hydrolase</td>
<td>14651</td>
</tr>
<tr>
<td>12908</td>
<td>0.0737323838716</td>
<td>0</td>
<td>Cnt</td>
<td>carnitine acetyltransferase</td>
<td>12908</td>
</tr>
<tr>
<td>75475</td>
<td>0.706364140164144</td>
<td>0</td>
<td>Cpt</td>
<td>S-oxoprolinase (ATP-hydrolysing)</td>
<td>75475</td>
</tr>
<tr>
<td>100039707</td>
<td>0.7268786847828243</td>
<td>0</td>
<td>Mthfrl</td>
<td>5, 10-methylene tetrahydrofolate synthetase- like</td>
<td>100039707</td>
</tr>
</tbody>
</table>

Figure 22. Detailed information section for GSEA results

![Gene set: GO:0006915 apoptotic process](image)

<table>
<thead>
<tr>
<th>User ID</th>
<th>Gene Symbol</th>
<th>Gene Name</th>
<th>Entrez Gene ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACIN1</td>
<td>ACIN1</td>
<td>apoptotic chromatin condensation inducer 1</td>
<td>22085</td>
</tr>
<tr>
<td>ADORA1</td>
<td>ADORA1</td>
<td>adenosine A1 receptor</td>
<td>134</td>
</tr>
<tr>
<td>AHI1</td>
<td>AHI1</td>
<td>Abelson helper integration site 1</td>
<td>54806</td>
</tr>
<tr>
<td>APC</td>
<td>APC</td>
<td>APC, WNT signaling pathway regulator</td>
<td>324</td>
</tr>
</tbody>
</table>

Figure 23. Detailed information section for ORA results
When the gene set has a network relationship between genes, such as TCGA co-expression network modules, there is also a button to show the network of the genes (Figure 24). This is reimplemented with Cytoscape.js library in the new version, removing the requirement of the obsolete Flash plugin.

![Gene network of some functional categories](image1)

**Figure 24.** Gene network of some functional categories

For analysis on WikiPathway and KEGG databases, external links lead to their viewer of the pathway with overlapping/leading edge genes highlighted. For GSEA runs against WikiPathway, the scores for the genes are also used to color genes in gradient (Figure 25).
Select an enriched gene set...

Figure 25. Link to WikiPathway viewer highlights genes with color gradient

For “other” organism, the result report will not have the GO Slim summary and gene table in detailed information section only list user IDs for input genes. But bar chart and volcano plot are still available, while the 2017 version just had a plain table of results.
8 Output report for NTA method

The NTA result page similarly starts with the job summary (Figure 26). The two side-by-side graphs show the retrieved or expanded network on the left and the DAG of GO Biological Process enrichment results. Below are several tables of seeds and information about enriched GO terms. Clicking on the red box in the DAG or in the flag icon in the table will zoom to the DAG node and color the corresponding genes in the network. Genes in the enriched GO category can be viewed by clicking the list icon. The result can be downloaded through the “Result Download” link including the HTML report and text files. The current view of the network and DAG can be saved as PNG files.
9 API for third party applications
9.1 Web API

WebGestalt 2019 provides APIs and programmatic access for interaction with hosted data and forwarding data from other websites for analysis.

<table>
<thead>
<tr>
<th>Endpoint</th>
<th>HTTP method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>/api/geneset</td>
<td>GET/POST</td>
<td>Get functional annotations e.g. GMT files</td>
</tr>
<tr>
<td>/api/reference</td>
<td>GET/POST</td>
<td>Get reference gene list used in ORA</td>
</tr>
<tr>
<td>/api/idmapping</td>
<td>GET/POST</td>
<td>Map gene IDs from one type to another</td>
</tr>
<tr>
<td>/</td>
<td>GET/POST</td>
<td>Prefill values in submission form</td>
</tr>
<tr>
<td>/process</td>
<td>POST</td>
<td>Submit job</td>
</tr>
</tbody>
</table>

/api/summary/[type]
- Returns a JSON of available data on WebGestalt. Data type could be 'idtype', 'geneset', 'referenceset', 'network', indicating supported ID mappings, gene set, reference set, and network (for NTA), respectively.
- HTTP method: GET/POST
- Parameters:
  - (optional) organism: 'athaliana', 'btaurus', 'celegans', 'cfamiliaris', 'drerio', 'sscrofa', 'dmelanogaster', 'ggallus', 'hsapiens', 'mmusculus', 'rnorwegicus', 'scerevisiae'

/api/geneset
- Returns gene set data files, i.e. GMT, description file, DAG edge list, network.
- HTTP method: GET/POST
- Parameters:
  - organism
  - dbType: database type, e.g. 'geneontology', 'pathway'. See summary results.
  - dbName: database name, e.g. 'Biological_Process', 'KEGG'. See summary results.
  - database: shorthand for "dbType_dbName".
  - fileType:
    - 'gmt': the functional annotation in GMT format.
    - 'des': a two-column file of gene set ID in GMT and its description.
    - 'dag': for some databases like GO, a DAG file with columns of parent and child relationship.
• 'net': for some databases like BioGrid, an edge list of genes in network modules.
  o (optional) ids: Just for datatype 'des', a subset of description is returned.

/api/reference
  • Returns reference set text file for ORA.
  • HTTP method: GET/POST
  • Parameters:
    o organism
    o referenceSet: name of the reference. See summary results.

/api/idmapping
  • Returns a JSON of ID mapping results from one ID type to another.
  • HTTP method: GET/POST
  • Parameters:
    o organism
    o sourceType: The ID type of input IDs. See supported types in summary results.
    o (optional) targetType: The ID type mapping to. Defaults to 'entrezgene'.
    o ids: The input IDs for mapping. A array when using POST, a comma concatenated string when using GET.
  • Example result:


    {
      "mapped": [  
        
        {
          "targetId": "A1BG",
          "sourceId": "1",
          "geneName": "alpha-1-B glycoprotein",
          "geneSymbol": "A1BG"
        }
      ],
      "unmapped": [  
        "1224899"
      ],
      "message": "Success",
      "status": 0,
      "sourceType": "entrezgene",
      "targetType": "genesymbol",
      "organism": "hsapiens",
      "standardId": "entrezgene"
    }

/  
  • Prefill values in the submission from to the WebGestalt server.
  • HTTP method: GET/POST with form data
  • Parameters: all optional
organism: athaliana, btaurus, celegans, cfamiliaris, dmelanogaster, drerio, ggallus, hsapiens, mmusculus, rnorvegicus, scerevisiae, sscrofa, others

enrich_method: ORA, GSEA, NTA

enriched_database_category: geneontology, pathway, network, disease, drug, phenotype, chromosomalLocation, community-contributed, others

enriched_database_name: Depends on enriched_database_category

id_type: ID type of the gene list
gene_list
ref_set: reference set (only supported now)
min_num: minimum number of genes for a category
max_num: maximum number of genes for a category
fdr_method
sig_method: top or fdr
sig_value: Example: Top 10 or FDR 0.05
per_num: permutation number for GSEA
collapse_method: method to collapse duplicated genes for GSEA
set_cover_num: number of sets when set cover algorithm stops
report_num: Number of categories visualized in the report
color_scheme: binary or continuous

process
- Direct POST form data to WebGestalt for analysis.
- Parameters: the same as the root /.

9.2 R package

WebGestalt 2019 also comes with a matched WebGestaltR package, which is available on CRAN. The package provides an R interface for running large batch of jobs and integrating into other pipelines. WebGestaltR also supports multiple databases and complete gene ontology sets for GSEA.

Below lists the documentation of the main function for enrichment analysis.

WebGestaltR: The R interface for enrichment analysis with WebGestalt.

Description: Main function for enrichment analysis

Usage: WebGestaltR(enrichMethod = "ORA", organism = "hsapiens", enrichDatabase = "geneontology_Biological_Process", enrichDatabaseFile = NULL, enrichDatabaseType = NULL, enrichDatabaseDescriptionFile = NULL, interestGeneFile = NULL, interestGene = NULL, interestGeneType = NULL, collapseMethod = "mean", referenceGeneFile = NULL,
Arguments

enrichMethod  Enrichment methods: ORA, GSEA or NTA.
organism  Currently, WebGestaltR supports 12 organisms. Users can use the function listOrganism to check available organisms. Users can also input others to perform the enrichment analysis for other organisms not supported by WebGestaltR. For other organisms, users need to provide the functional categories, interesting list and reference list (for ORA method). Because WebGestaltR does not perform the ID mapping for the other organisms, the above data should have the same ID type.
enrichDatabase  The functional categories for the enrichment analysis. Users can use the function listGeneSet to check the available functional databases for the selected organism. Users can also input others to provide a custom functional databases not supported by WebGestaltR for the selected organism.
enrichDatabaseFile  If users set organism as others or set enrichDatabase as others, users need to provide a GMT file as the functional category for enrichment analysis. The WebGestaltR 13 extension of the file should be gmt and the first column of the file is the category ID, the second one is the external link for the category. Genes annotated to the category are from the third column. All columns are separated by tabs.
enrichDatabaseType  If users set enrichDatabase as others, WebGestaltR will also perform ID mapping for the supplied GMT file. Thus, users need to set the ID type of the genes in the enrichDatabaseFile. If users set organism as others, users do not need to set this ID type because WebGestaltR will not perform ID mapping for other organisms. The supported ID types of WebGestaltR for the selected organism can be found by the function listIdType.
enrichDatabaseDescriptionFile  Users can also provide a description file for the custom enrichDatabaseFile. The extension of the description file should be des. The description file contains two columns: the first column is the category ID that should be exactly the same as the category ID in the custom enrichDatabaseFile and the second column is the description of the category. All columns are separated by tabs.
interestGeneFile  If enrichMethod is ORA or NTA, the extension of the interestGeneFile should be txt and the file can only contain one column: the interesting gene list. If enrichMethod is GSEA, the extension of the interestGeneFile should be rnk and the file should contain two columns separated by tab: the gene list and the corresponding scores. Users can also use an R object as the input. If enrichMethod is ORA or NTA, interestGene should be an R vector object containing the interesting gene list. If enrichMethod is GSEA, interestGene should be an R data.frame object containing two columns: the gene list and the corresponding scores.
interestGeneType  The ID type of the interesting gene list. The supported ID types of WebGestaltR for the selected organism can be found by the function listIdType. If the organism is others, users do not need to set this parameter. collapseMethod  The method to collapse duplicate IDs with scores. mean, median, min and max represent the mean, median, minimum and maximum of scores for the duplicate IDs.
referenceGeneFile  For the ORA method, the users need to upload the reference gene list. The extension of the referenceGeneFile should be txt and the file can only contain one column: the reference gene list.
referenceGene: For the ORA method, users can also use an R object as the reference
gene list. referenceGene should be an R vector object containing the reference gene
list.
referenceGeneType: The ID type of the reference gene list. The supported ID types of
WebGestaltR for the selected organism can be found by the function listIdType. If the
organism is others, users do not need to set this parameter.
referenceSet: Users can directly select the reference set from existing platforms in
WebGestaltR and do not need to provide the reference set through referenceGeneFile.
All 14 WebGestaltR existing platforms supported in WebGestaltR can be found by the
function listReferenceSet. If referenceGeneFile and referenceGene are NULL,
WebGestaltR will use the referenceSet as the reference gene set. Otherwise,
WebGestaltR will use the user supplied reference set for enrichment analysis.
minNum: WebGestaltR will exclude the categories with the number of annotated genes
less than minNum for enrichment analysis. The default is 10.
maxNum: WebGestaltR will exclude the categories with the number of annotated genes
larger than maxNum for enrichment analysis. The default is 500.
sigMethod: Two methods of significance are available in WebGestaltR: fdr and top. fdr
means the enriched categories are identified based on the FDR and top means all
categories are ranked based on FDR and then select top categories as the enriched
categories. The default is fdr.
fdrMethod: For the ORA method, WebGestaltR supports five FDR methods: holm, hochberg,
hommel, bonferroni, BH and BY. The default is BH.
fdrThr: The significant threshold for the fdr method. The default is 0.05.
topThr: The threshold for the top method. The default is 10.
reportNum: The number of enriched categories visualized in the final report. The
default is 20. A larger reportNum may be slow to render in the report.
permNum: The number of permutations for the GSEA method. The default is 1000.
isOutput: If isOutput is TRUE, WebGestaltR will create a folder named by the
projectName and save the results in the folder. Otherwise, WebGestaltR will only
return an R data.frame object containing the enrichment results. If hundreds of gene
list need to be analyzed simultaneously, it is better to set isOutput to FALSE. The
default is TRUE.
outputDirectory: The output directory for the results.
projectName: The name of the project. If projectName is NULL, WebGestaltR will use
time stamp as the project name.
dagColor: If dagColor is binary, the significant terms in the DAG structure will be
colored by steel blue for ORA method or steel blue (positive related) and dark orange
(negative related) for GSEA method. If dagColor is continuos, the significant terms
in the DAG structure will be colored by the color gradient based on corresponding
FDRs.
setCoverNum: The number of expected gene sets after set cover to reduce redundancy. It
could get fewer sets if the coverage reaches 100%. The default is 10.
setCoverMethod: Netowrk construction method for NTA. Either
Network_Retrieval_Prioritization or Network_Expansion. Network Retrieval &
Prioritization first uses random walk analysis to calculate random walk probabilities
for the input seeds, then identifies the relationships among the seeds in the
selected network and returns a retrieval sub-network. The seeds with the top random
walk probabilities are highlighted in the sub-network. Network Expansion first uses
random walk analysis to rank all genes in the selected network based on their network
proximity to the input seeds and then return an expanded sub-network in which nodes
are the input seeds and their top ranking neighbors and edges represent their
relationships.
neighborNum: The number of neighbors to include in NTA Network Expansion method.
highlightType: The type of nodes to highlight in the NTA Network Expansion method,
either Seeds or Neighbors.
*highlightSeedNum* The number of top input seeds to highlight in NTA Network Retrieval & Prioritization method.

*nThreads* The number of cores to use for GSEA and set cover, and in batch function.

*hostName* The server URL for accessing data. Mostly for development purposes.

**Details** WebGestaltR function can perform three enrichment analyses: ORA (Over-Representation Analysis) and GSEA (Gene Set Enrichment Analysis) and NTA (Network Topology Analysis). Based on the user-uploaded gene list or gene list with scores, WebGestaltR function will first map the gene list to the entrez gene ids and then summarize the gene list based on the GO (Gene Ontology) Slim. After performing the enrichment analysis, WebGestaltR function also returns a user-friendly HTML report containing GO Slim summary and the enrichment analysis result. If functional categories have DAG (directed acyclic graph) structure or genes in the functional categories have network structure, those relationship can also be visualized in the report.

**Value** The WebGestaltR function returns a data frame containing the enrichment analysis result and also outputs an user-friendly HTML report if isOutput is TRUE. The WebGestaltRBatch function returns a list of enrichment results.

**Examples**

```
####### ORA example #########
geneFile <- system.file("extdata", "interestingGenes.txt", package="WebGestaltR")
refFile <- system.file("extdata", "referenceGenes.txt", package="WebGestaltR")
outputDirectory <- getwd()
enrichResult <- WebGestaltR(enrichMethod="ORA", organism="hsapiens",
enrichDatabase="pathway_KEGG", interestGeneFile=geneFile,
interestGeneType="genesymbol", referenceGeneFile=refFile,
referenceGeneType="genesymbol", isOutput=TRUE, outputDirectory=outputDirectory,
projectName=NULL)

####### GSEA example #########
rankFile <- system.file("extdata", "GeneRankList.rnk", package="WebGestaltR")
outputDirectory <- getwd()
enrichResult <- WebGestaltR(enrichMethod="GSEA", organism="hsapiens", weightedSetCover enrichDatabase="pathway_KEGG", interestGeneFile=rankFile,
interestGeneType="genesymbol", sigMethod="top", topThr=10, minNum=5,
outputDirectory=outputDirectory)

####### NTA example #########
enrichResult <- WebGestaltR(enrichMethod="NTA", organism="hsapiens",
enrichDatabase="network_PPI_BIOGRID", interestGeneFile=geneFile,
interestGeneType="genesymbol", sigMethod="top", topThr=10, outputDirectory=getwd(),
highlightSeedNum=10, networkConstructionMethod="Network_Retrieval_Prioritization")
```
Appendix. Algorithm details of redundancy reduction

Affinity Propagation

Given a list of input gene sets, the affinity propagation algorithm clusters similar gene sets into groups and identifies one exemplar that best represents each group. The affinity propagation algorithm splits the gene sets such that each partition is associated with its most representative gene set (called “exemplar”). At the same time, the sum of the user-defined similarity measures between gene sets and their exemplars and the exemplars’ prior preference to be designated as exemplars is maximized. This is achieved by simultaneously considering all gene sets as potential exemplars and exchanging messages between gene sets until a satisfying set of exemplars and clusters emerges. The algorithm takes as input a real valued similarity matrix $M$ where $M_{ij}$ implies the appropriateness of selecting gene set $j$ to be the exemplar for gene set $i$. We use the following formula to set $M$:

$$m_{ij} = \begin{cases} \text{Jaccard}(i, j) & \text{if Jaccard}(i, j) > 0 \\ -\infty & \text{if Jaccard}(i, j) = 0 \end{cases}$$

In other words, if a pair of gene sets $i$ and $j$ overlap, we set its Jaccard distance as its similarity. Otherwise, its similarity is set to $-\infty$. Intuitively, it is not appropriate for gene set $i$ to represent gene set $j$ if they do not overlap. Besides the similarity matrix, another important parameter of the algorithm is the input preference. This can be interpreted as the suitability of a gene set to become an exemplar. The input preference can either be customized for each gene set or it can be set to the same value shared among all gene sets. It has the effect of adjusting the graininess of the resulting clusters where large input preference values can result in a large number of clusters. We use the following procedure to set the preference values. Assume that the gene set enrichment significance levels, i.e., $-\log(p\text{-value})$, are in the range of $[p_{\text{min}}, p_{\text{max}}]$ and let $m_{\text{med}}$ denote the median of all finite values in the similarity matrix $M$. We set the maximum of preference to $m_{\text{med}}$ and the minimum to 0. For gene set $i$, its input preference is interpolated linearly as:

$$ip_i = \frac{m_{\text{med}}(x-p_{\text{min}})}{p_{\text{max}}-p_{\text{min}}}, \text{ where } x = -\log(p\text{-value}_i),$$

For gene sets with a large significance level, it is preferable to increase its tendency to be selected as an exemplar. The R package “apcluster” is used for the heavy lifting.

Weighted Set Cover

Given a universe of finite set $U$ with $|U| = n$ and sets $C = \{C_1, \ldots, C_m\} \subseteq U$, a set cover is a collection $S$ of some of the sets from $C$ whose union is the entire universe. Here, $C$ corresponds to all gene sets of interest, and $U$ corresponds to the union of all genes
within these gene sets. We consider a generalized version of weighted set cover and maximum coverage called size-constrained weighted set cover where each set is also associated with a weight $w_i$, which is calculated as $-\log(p\text{-value})$. Therefore, higher weights are assigned to gene sets with smaller enrichment p values. The input to the problem further includes a size constraint $k$. The goal is to find $S$, a sub-collection of up to $k$ sets, whose sum of weights is maximal and whose union covers as many elements as possible. Assume that one or more sets have been selected into $S$. We denote the marginal benefit set of a candidate set $s$ given $S$, $B_m(s, S)$ as the set of elements from $U$ covered by $s$ but have not yet been covered by any set in $S$. In addition, we define the marginal gain of selecting $s$ into $S$ as $G_m(s, S) = |B_m(s, S)|w_s$. The algorithm starts with computing the marginal benefit set for all sets in $C$. Next, it selects the set with maximal marginal gain and adds it to the solution $S$. The algorithm then updates the marginal benefit set of the remaining candidate sets and removes those candidates with empty marginal benefit set before repeating the selection step. The algorithm returns as soon as it has covered all elements in $U$ or after $k$ iterations. It outputs the selected sets and fraction of coverage $\hat{s}$.