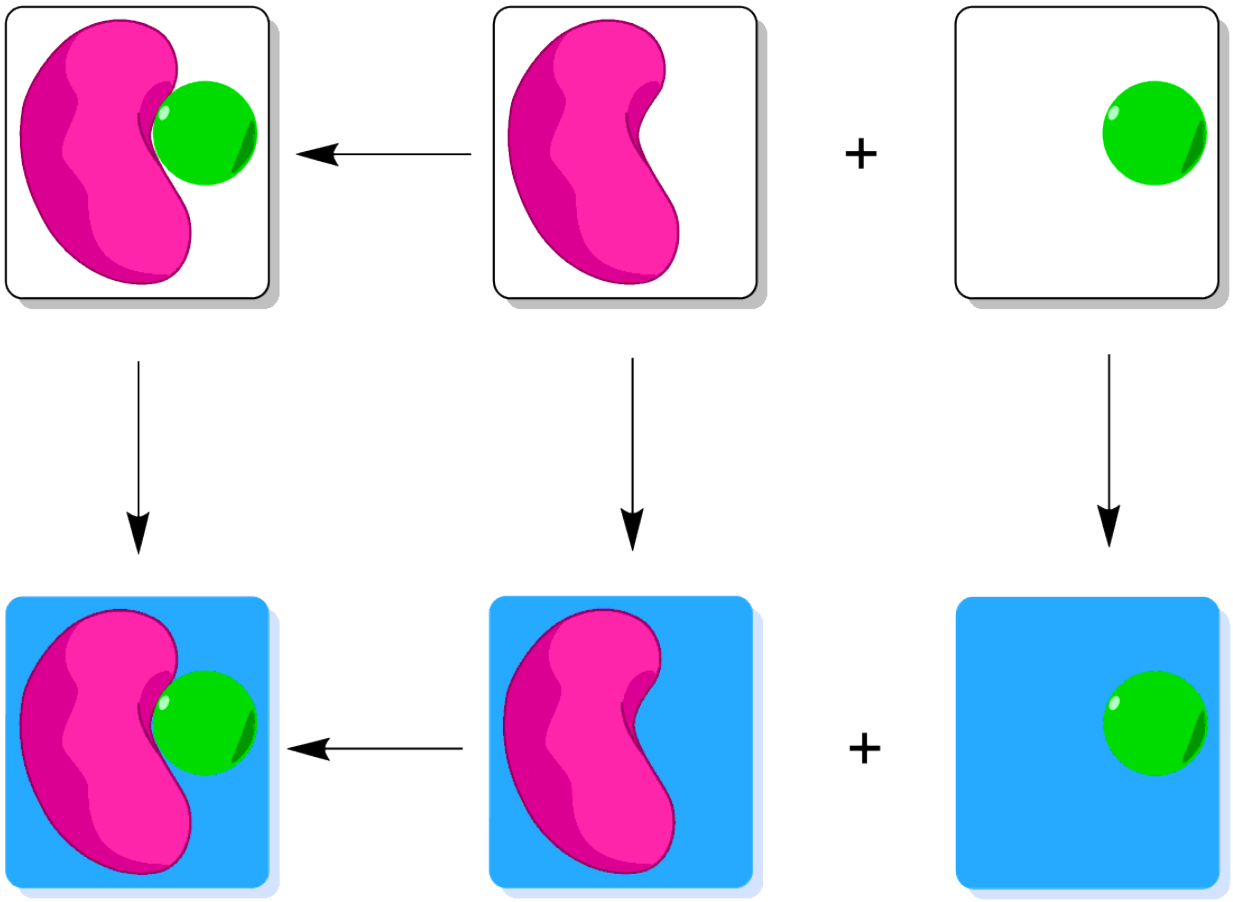

CaFE Manual

Release 1.0

Hui Liu, Tingjun Hou

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CONTENTS

CHAPTER

ONE

INSTALLATION

1.1 Prerequisites

- VMD 1.9.2 or later

Note: There is a bug in the `topotools1.5` plugin, which is included in VMD 1.9.2 and invoked by CaFE. You should change line 43 in:

Linux/MacOSX

`$VMDDIR/lib/plugins/noarch/tcl/topotools1.5/topoatoms.tcl`

Windows

`$VMDDIR/plugins/noarch/tcl/topotools1.5/topoatoms.tcl`

from:

```
$s set element [lindex $elements [ptefrommass $idx]]
```

to:

```
$s set element [lindex $elements [ptefrommass $a]]
```

Alternatively, you can copy the corrected `topoatoms.tcl` file in the `patch` folder, which is distributed with the CaFE source code, and replace the associated file in the `topotools1.5` plugin folder in your installed VMD distribution.

- NAMD 2.9 or later
- APBS 1.3 or later

  Optionally, for MM/PBSA only
- DelPhi 5.1 or later

  Optionally, for MM/PBSA only

All these tools are commonly used in molecular simulations, please download the installation files and follow the corresponding instructions on their websites. Make sure that all the folders containing the binary files are appended to the `PATH` environment variable.

1.2 Download and install

After installing the above required programs, you could download the CaFE source code: `CaFE_Plugin-master.zip` from https://github.com/HuiLiuCode/CaFE_Plugin.

If you have root access for installation, just extract the compressed contents and rename the `src` folder to `cafe1.0` and copy it to `$VMDDIR/lib/plugins/noarch/tcl` (Linux/MacOSX) or `$VMDDIR/plugins/noarch/tcl` (Windows), where `$VMDDIR` is the directory in which VMD installed.

If you don't have root access, try to extract the contents and rename the `src` folder to `cafe1.0` and copy it to somewhere in your `$HOME` directory. Then, add the following to the VMD start-up file `$HOME/.vmdrc` (Linux/MacOSX) or `vmd.rc` (Windows):

```
set auto_path [linsert $auto_path 0 {/PATH/TO/YOUR/FOLDER}]
```

CHAPTER

TWO

APPLICATIONS

CaFE is an automatic pipeline tool for post-processing and energetic analysis, which is powered by VMD *[HW96]* (page 14). Prior to the calculations, topology and trajectory files are needed to be generated by common molecular dynamics (MD) simulation software. Currently, AMBER *[CD05]* (page 14) and NAMD *[PJ05]* (page 14) are generally supported. Other simulation packages using the same topology files are supported, too.

Note: If AMBER is used, you'd better set "`iwrap=1`" in the input file or use *cpptraj* to "`image`" the generated trajectory. If NAMD is used, you'd better set "`wrapAll on`" in the configuration file.

CaFE is implemented as a set of Tcl scripts. When using it, you should import the *cafe* package by appending the following line in the analysis scripts first:

```
package require cafe 1.0
```

After that, two major procedures can be invoked for binding free energy calculations.

2.1 The *mmpbsa* procedure

The **`mmpbsa`** procedure automates post-processing and energetic analysis using the molecular mechanics Poisson-Boltzmann surface area (MM/PBSA) method *[KP00]* (page 14). A trajectory file containing the binding complex is required, and then the receptor and ligand will be extracted from that according to the one-trajectory protocol *[KP00]* (page 14). For MM/PBSA calculations, either APBS *[BN01]* (page 14) or DelPhi *[LL12]* (page 14) is needed to be installed.

2.1.1 Usage

```
mmpbsa -top file -trj file [-args ...]
```

Mandatory arguments

- **-top**: topology file name

  available values: a valid file name

  default value: none

- **-trj**: trajectory file name

  available values: a valid file name

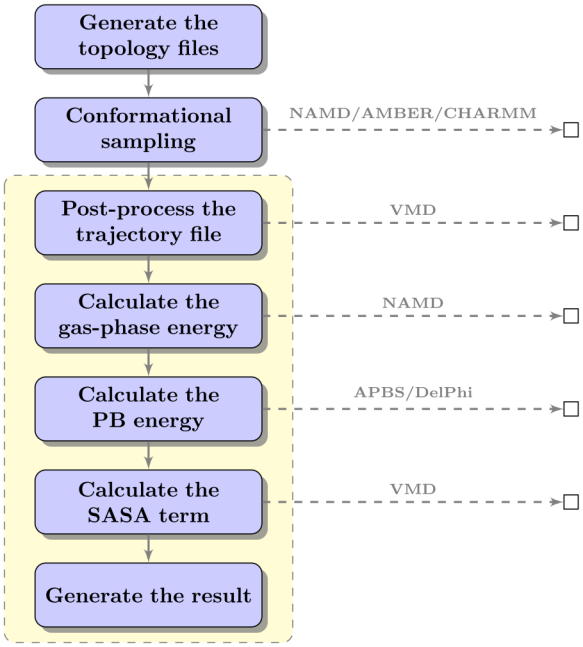

Fig. 2.1: **Work flow for MM/PBSA calculations**. The procedures in yellow background are automated by CaFE.

default value: none

Optional arguments

- **-top_type**: topology file type

  available values: `parm7` (AMBER format), `psf` (CHARMM/NAMD format), `auto`

  default value: `auto`

- **-trj_type**: trajectory file type

  available values: all of the coordinate and trajectory file types supported by VMD

  default value: `auto`

- **-par**: CHARMM-formatted force field parameter file, required only if the PSF topology type is used

  available values: a valid file name

  default value: `$CAFEDIR/par_all22_prot.inp`

- **-out**: output file name

  available values: a valid file name

  default value: `result.log`

- **-debug**: debug level

  available values: `0` (remove all of the intermediate files), `1` (remove a part of them), `2` (keep all)

  default value: `0`

- **-first**: the first frame index, starting from `0`

  available values: an integer >= `0`

  default value: `0`
- **-last**: the last frame index, starting from `0`

  available values: an integer >= `0` or `-1` (stands for the last frame of the trajectory)

  default value: `-1`
- **-stride**: stride

  available values: an integer >= `1`

  default value: `1`
- **-com**: complex selection

  available values: a valid selection string used by VMD

  default value: `""`
- **-rec**: receptor selection

  available values: a valid selection string used by VMD

  default value: `""`
- **-lig**: ligand selection

  available values: a valid selection string used by VMD

  default value: `""`
- **-mm**: do gas-phase calculations or not

  available values: `0` (do not) or `1` (do)

  default value: `0`
- **-mm_exe**: path to the NAMD binary

  available values: a valid path

  default value: `"namd2"`
- **-mm_diel**: dielectric constant

  available values: a float

  default value: `1.0`
- **-pb**: do PB calculations or not

  available values: `0` (do not), `1` (use DelPhi), `2` (use APBS)

  default value: `0`
- **-pb_exe**: path to the DelPhi/APBS binary

  available values: a valid path

  default value: `"delphi77"`
- **-pb_siz**: radii parameter file, not a necessity (DelPhi-only)

  available values: a valid file name

  default value: `""`

- **-pb_crg**: charge parameter file, not a necessity (DelPhi-only)

  available values: a valid file name

  default value: `""`

- **-pb_rad**: type of PB radii

  available values: `bondi`, `rowland`, `mparse`, `parse`, `charmm`, `roux`, `parm7` (valid only if the topology is an AMBER parm7 file, using the radii included in it)

  default value: `bondi`

- **-pb_indi**: internal dielectric constant

  available values: a float

  default value: `1.0`

- **-pb_exdi**: external dielectric constant

  available values: a float

  default value: `80.0`

- **-pb_scale**: the reciprocal of grid spacing

  available values: a float

  default value: `2.0`

- **-pb_perfil**: percentage of filling

  available values: a float

  default value: `80.0`

- **-pb_prbrad**: probe radius

  available values: a float

  default value: `1.4`

- **-pb_linit**: max number for linear iterations

  available values: an integer > `3`

  default value: `1000`

- **-pb_maxc**: convergence threshold

  available values: a float > `0.0`

  default value: `0.0001`

- **-pb_bndcon**: boundary condition (DelPhi-only)

  available values: `1` (zero boundary condition), `2` (dipolar), `4` (coulombic)

  default value: `4`

- **-pb_bcfl**: boundary condition (APBS-only)

  available values: `zero` (zero boundary condition), `sdh` (single Debye-Huckel), `mdh` (multiple Debye-Huckel)

  default value: `sdh`

- **-pb_chgm**: the method that charges are mapped to the grids (APBS-only)

  available values: `spl0` (linear splines), `spl2` (cubic B-spline), `spl4` (quintic B-spline)

  default value: `spl0`

- **-pb_srfm**: the model used to construct the dielectric and ion-accessibility coefficients (APBS-only)

  available values: `mol`, `smol`, `spl2`, `spl4`

  default value: `smol`

- **-pb_swin**: spline window width (APBS-only)

  available values: a float > `0.0`

  default value: `0.3`

- **-pb_sdens**: density of grids (APBS-only)

  available values: a float > `0.0`

  default value: `10.0`

- **-sa**: do SA calculations or not

  available values: `0` (do not), `1` (use VMD)

  default value: `0`

- **-sa_rad**: type of SA radii

  available values: `bondi`, `rowland`, `mparse`, `parse`, `charmm`, `roux`, `parm7` (valid only if the topology is an AMBER parm7 file, using the radii included in it)

  default value: `bondi`

- **-sa_gamma**: surface tension

  available values: a float

  default value: `0.005`

- **-sa_beta**: surface offset

  available values: a float

  default value: `0.0`

- **-sa_prbrad**: probe radius

  available values: a float

  default value: `1.4`

- **-sa_samples**: number of samples

  available values: an integer > `0`

  default value: `500`

For more details about the parameters, please see the manuals of VMD (supported file types, selection string, SA calculations) and APBS/DelPhi (PB calculations).

2.1.2 Example

Now, suppose that we have performed the conformational sampling by using MD simulations, there are two folders in the working folder `workdir`:

1. `md`, which contains topology file `com.psf`, and generated trajectory `com.dcd`;
2. `toppar`, which contains force field parameter files.

In the PSF file, the receptor and ligand have been put into segments named "PRO" and "LIG", respectively. The trajectory file is totally 1 ns long and saved every 100 ps. We want to perform MM/PBSA calculations from 0 to 1 ns and produce snapshots every 100 ps. APBS is used in the PB calculations.

A typical analysis script is something like this:

```
package require cafe 1.0

mmpbsa -top       ../md/com.psf \
       -trj       ../md/com.dcd \
       -out       mmpbsa.log \
       -par       ../toppar/par_all22_prot.prm \
       -par       ../toppar/par_all36_cgenff.prm \
       -par       ../toppar/toppar_water_ions_namd.str \
       -par       ../toppar/lig.str \
       -com       "segname PRO LIG" \
       -rec       "segname PRO" \
       -lig       "segname LIG" \
       -first     0 \
       -last      -1 \
       -stride    1 \
       -mm        1 \
       -pb        2 \
       -pb_exe    apbs \
       -pb_rad    mparse \
       -pb_bcfl   mdh \
       -pb_chgm   spl2 \
       -sa        1 \
       -sa_rad    mparse \
       -sa_gamma  0.00542 \
       -sa_beta   0.92

quit
```

Create a new folder `mmpbsa` in `workdir` and save the above contents to a file named `mmpbsa.vmd` in it.

Note: Don't forget the backslash!

Then run commands as follows in the terminal, which will perform the MM/PBSA calculations and generate results in plain text:

```
$ cd workdir/mmpbsa
$ vmd -dispdev text -eofexit < mmpbsa.vmd > vmd.log
```

The output file `mmpbsa.log`, which contains the calculated binding free energy, is self-explanatory. Files that are required to perform the exemplified calculations are in the `examples` folder alongside with the source code.

2.2 The *lie* procedure

The **lie** procedure automates post-processing and energetic analysis using the linear interaction energy (LIE) method *[AJ94]* (page 14). Two topology as well as MD trajectory files containing the solvated complex and ligand are required.

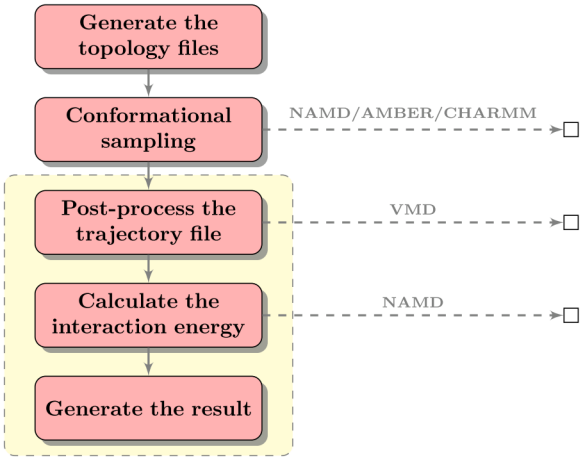

Fig. 2.2: **Work flow for LIE calculations.** The procedures in yellow background are automated by CaFE.

2.2.1 Usage

```
lie -top_bound file -trj_bound file -top_free file -trj_free file [-args ...]
```

Mandatory arguments

- **-top_bound**: topology file name for the bound state

  available values: a valid file name

  default value: none
- **-trj_bound**: trajectory file name for the bound state

  available values: a valid file name

  default value: none
- **-top_free**: topology file name for the free state

  available values: a valid file name

  default value: none
- **-trj_free**: trajectory file name for the free state

  available values: a valid file name

  default value: none

Optional arguments

- **-top_type**: topology file type
  available values: `parm7` (AMBER format), `psf` (CHARMM/NAMD format), `auto`
  default value: `auto`
- **-trj_type**: trajectory file type
  available values: all of the coordinate and trajectory file types supported by VMD
  default value: `auto`
- **-par**: CHARMM-formatted force field parameter file, required only if the PSF topology type is used
  available values: a valid file name
  default value: `$CAFEDIR/par_all22_prot.inp`
- **-out**: output file name
  available values: a valid file name
  default value: `result.log`
- **-debug**: debug level
  available values: `0` (remove all of the intermediate files), `1` (remove a part of them), `2` (keep all)
  default value: `0`
- **-first_bound**: the first frame index for the bound state, starting from `0`
  available values: an integer >= `0`
  default value: `0`
- **-last_bound**: the last frame index for the bound state, starting from `0`
  available values: an integer >= `0` or `-1` (stands for the last frame of the trajectory)
  default value: `-1`
- **-stride_bound**: stride for the bound state
  available values: an integer >= `1`
  default value: `1`
- **-lig_bound**: ligand selection for the bound state
  available values: a valid selection string used by VMD
  default value: `""`
- **-first_free**: the first frame index for the free state, starting from `0`
  available values: an integer >= `0`
  default value: `0`
- **-last_free**: the last frame index for the free state, starting from `0`
  available values: an integer >= `0` or `-1` (stands for the last frame of the trajectory)
  default value: `-1`

- **-stride_free**: stride for the free state

  available values: an integer >= `1`

  default value: `1`

- **-lig_free**: ligand selection for the free state

  available values: a valid selection string used by VMD

  default value: `""`

- **-mm_exe**: path to the NAMD binary

  available values: a valid path

  default value: `"namd2"`

- **-alpha**: van der Waals coefficient

  available values: a float

  default value: `0.18`

- **-beta**: electrostatic coefficient

  available values: a float

  default value: `0.33`

- **-gamma**: offset

  available values: a float

  default value: `0.0`

For more details about the parameters, please see the manual of VMD (supported file types, selection string).

2.2.2 Example

Now, suppose that we have performed the conformational sampling by using MD simulations, there are two folders in the working folder `workdir`:

1. `md`, which contains topology files `com.psf` and `lig.psf`, and generated trajectories `com.dcd` and `lig.dcd`;
2. `toppar`, which contains force field parameter files.

In both the PSF files, the ligand has been put into a segment named "LIG". Each of the two trajectory files is 1 ns long and saved every 100 ps. We want to perform LIE calculations from 0 to 1 ns and produce snapshots every 100 ps.

A typical analysis script is something like this:

```
package require cafe 1.0

lie -top_bound    ../md/com.psf \
    -trj_bound    ../md/com.dcd \
    -top_free     ../md/lig.psf \
    -trj_free     ../md/lig.dcd \
    -out          lie.log \
    -par          ../toppar/par_all22_prot.prm \
    -par          ../toppar/par_all36_cgenff.prm \
    -par          ../toppar/toppar_water_ions_namd.str \
```

```
    -par          ../toppar/lig.str \
    -lig_bound    "segname LIG" \
    -lig_free     "segname LIG" \
    -first_bound  0 \
    -last_bound   -1 \
    -stride_bound 1 \
    -first_free   0 \
    -last_free    -1 \
    -stride_free  1 \
    -alpha        0.18 \
    -beta         0.5 \
    -gamma        0.0

quit
```

Note: The values of `alpha`, `beta` and `gamma` are dependent on your simulated systems. Please see related references for the choice of values.

Create a new folder `lie` in `workdir` and save the above contents to a file named `lie.vmd` in it.

Note: Don't forget the backslash!

Then run commands as follows in the terminal, which will perform the LIE calculations and generate results in plain text:

```
$ cd workdir/lie
$ vmd -dispdev text -eofexit < lie.vmd > vmd.log
```

The output file `lie.log`, which contains the calculated binding free energy, is self-explanatory. Files that are required to perform the exemplified calculations are in the `examples` folder alongside with the source code.

CHAPTER

THREE

ABOUT CAFE

CaFE is a free and open-source VMD plugin for binding affinity prediction using end-point free energy methods. It is being developed in Hou Lab at Zhejiang University.

3.1 Citation

If CaFE is utilized in scientific work that results in a publication, it is expected that the following reference is cited:

> Liu H, Hou T.
> CaFE: a tool for binding affinity prediction using end-point free energy methods.
> *In submission*

3.2 License

CaFE is freely available under the GPL License:

```
CaFE: Calculation of Free Energy

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```

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[BN01] Baker, N.A., et al. (**2001**) Electrostatics of nanosystems: Application to microtubules and the ribosome, *Proc. Natl. Acad. Sci.*, 98, 10037-10041.

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[AJ94] Åqvist, J., Medina, C. and Samuelsson, J.-E. (**1994**) A new method for predicting binding affinity in computer-aided drug design, *Protein Eng.*, 7, 385-391.

[HW96] Humphrey, W., Dalke, A. and Schulten, K. (**1996**) VMD: Visual molecular dynamics, *J. Mol. Graph.*, 14, 33-38.

[PJ05] Phillips, J.C., et al. (**2005**) Scalable molecular dynamics with NAMD, *J. Comput. Chem.*, 26, 1781-1802.

[CD05] Case, D.A., et al. (**2005**) The amber biomolecular simulation programs, *J. Comput. Chem.*, 26, 1668-1688.