

Structural Bioinformatics – Molecular Dynamics simulations

Tue 25 Oct 2022

Goal: perform MD simulations of two simple systems and perform some analysis.

PART ONE: MD simulation of water

In this case you will perform a short MD simulation of a small water box and then calculate some specific properties. In the following figures you see some definition for common properties that are analyzed in liquids.



Radial Distribution Function

The structure of a fluid can be defined by the distribution functions of the atomic positions, of which the first is the density and the second is the pair distribution function. This is the probability of finding a pair of atoms at a given distance r with respect to a uniform distribution.

$$\rho_N^{(1)}(\mathbf{r}) = \left\langle \sum_{i=1}^N \delta(\mathbf{r} - \mathbf{r}_i) \right\rangle.$$

Density

$$\rho_N^{(2)}(\mathbf{r}, \mathbf{r}') = \left\langle \sum_{i=1}^N \sum_{j=1, j \neq i}^N \delta(\mathbf{r} - \mathbf{r}_i) \delta(\mathbf{r}' - \mathbf{r}_j) \right\rangle.$$

Density of pairs

i.e. one can find N particles and $N(N-1)$ pairs of particles in the total volume, respectively.

$$g_N^2(\mathbf{r}_1, \mathbf{r}_2) = \rho_N^{(2)}(\mathbf{r}_1, \mathbf{r}_2) / (\rho_N^{(1)}(\mathbf{r}_1) \rho_N^{(1)}(\mathbf{r}_2)) = \frac{\rho_N^{(2)}(|\mathbf{r}_1 - \mathbf{r}_2|)}{\rho^2}$$

So that $\rho g(r)$ is the conditional probability to find another particle at a distance r away from the origin.

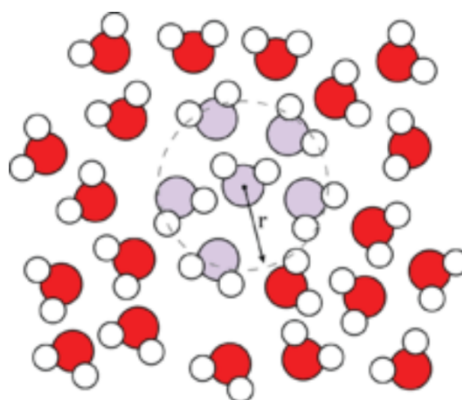
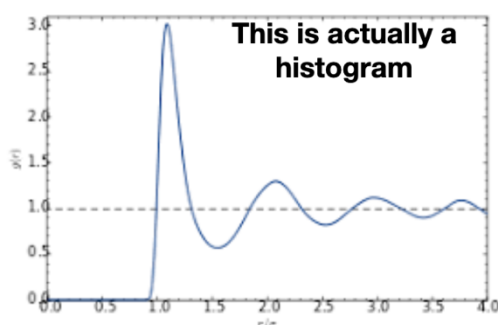


Radial Distribution Function

1. Calculate the distances between all couples of oxygens for example
2. Make an histogram
3. Make the average histogram over the trajectory
4. Multiply by V/N^2

$$g(r) = \rho^{(2)}(|r_1 - r_2|) \frac{V^2}{N^2} = n^{(2)}(|r_1 - r_2|) \frac{V}{N^2}$$

Larger than 1 means that at that distance is more dense than a homogeneous liquid
Smaller than 1 means that is less dense



Enthalpy of Vaporisation

Is the enthalpy difference between a liquid and a gas form for a molecule

$$\Delta H_{\text{vap}}(T) = H(p, T)_{\text{gas}} - H(p, T)_{\text{liquid}} = E_{\text{gas}} - E_{\text{liquid}} + p(V_{\text{gas}} - V_{\text{liquid}}),$$

Total energies and volumes in the two phases.

Under the assumption that the gas is ideal (potential energy $U_{\text{gas}}=0$, $PV=nRT$), and that the kinetic energies of a molecule in the gas and liquid phases are identical at a given temperature T , one obtains:

$$\begin{aligned} \Delta H_{\text{vap}}(T) &\approx -\langle U(p, T)_{\text{liquid}} \rangle / N + p(V_{\text{gas}} - \langle V_{\text{liquid}} \rangle) + C \\ &\approx -\langle U(p, T)_{\text{liquid}} \rangle / N + RT - p\langle V_{\text{liquid}} \rangle + C, \end{aligned}$$

These are all quantities available from a simulation. C is a generic correction term.

Heat Capacity at constant pressure



How much heat is needed to increase the temperature

$$c_p = \left(\frac{\partial H}{\partial T} \right)_p$$

Definition. Calculate the Enthalpy at multiple temperatures, interpolate it with some smooth function and then differentiate it.

$$c_p \approx \frac{\langle H_2 \rangle - \langle H_1 \rangle}{T_2 - T_1}$$

Numerical differentiation over a range of temperature of interest.

$$c_p = \frac{\langle H^2 \rangle - \langle H \rangle^2}{Nk_B \langle T \rangle^2}$$

Using the **fluctuation-dissipation** formula. (This is the only way to get one value from a single simulation, but to obtain the curve methods 1 or 2 are needed).

PART TWO: MD simulation of alanine dipeptide

For the second simulation you will use alanine dipeptide and calculate properties related to the Ramachandran's distribution.

As for task 1 at the end of the notebook you will find the instructions to generate a report for this second lab experience.