Modeling Weak Interactions With Spherical Atomic Electron Densities

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Traditional force fields use a Lennard-Jones potential and point charges to model weak interactions in atomistic simulations, e.g. of biomolecules [1] or porous materials. [2] Such models involve numerous empirically adjusted parameters, which can be statistically estimated on a case-by-case basis. This is not only a daunting task, it is also difficult to guarantee *a priori* that such empirically adjusted parameters will be reliable in every use case, e.g. due to over-fitting. In order to limit the risk of over-fitting, we propose a new additive force field for weak interactions, whose primary objective is to contain as little as possible adjustable parameters. Our new model expresses intermolecular interactions in terms of integrals of electron densities of the non-interacting fragments, and is hence called the Monomer Electron Density Force Field (MEDFF). [3] The interaction energy comprises four terms in line with Symmetry-Adapted Perturbation Theory: electrostatics, exchange repulsion, induction and dispersion, of which the latter three MEDFF terms contain one linear adjustable parameter each. These parameters were fitted to SAPT/Aug-cc-pVTZ data for the S66x8 database of molecular dimers and were further refined to CCSD(T)/CBS energies of the same dimers. [4] MEDFF performs remarkably well for dispersion-dominated interactions, but due to its additive structure, it shares some typical weaknesses of non-polarizable force fields. MEDFF employs approximate electron densities, sums of spherical atoms, for the sake of computational efficiency. The spherical atoms are expressed as a sum of exponential density functions, at most one for each atomic shell, such that all integrals in MEDFF can be computed analytically at a typical force-field cost. The sum of exponential functions is derived from a reference electron density with the Minimal Basis Iterative Stockholder (MBIS) method. [5] As opposed to traditional density fitting, MBIS uses the Kullback-Leibler divergence as a loss function and it can therefore also be interpreted as a variant of the Hirshfeld partitioning method.

References

1. K. Vanommeslaeghe *et al.*, *J. Comput. Chem.* **31** (2010), 671.
2. D. E. Coupry, M. A. Addicoat, and T. Heine, *J. Chem. Theory Comput.* **12** (2016), 5215.
3. S. Vandenbrande, M. Waroquier, V. V. Speybroeck, and T. Verstraelen, *J. Chem. Theory Comput.* **13** (2017), 161.
4. J. Řezáč, K. E. Riley, and P. Hobza, *J. Chem. Theory Comput.* **7** (2011), 2427.
5. T. Verstraelen, S. Vandenbrande, F. Heidar-Zadeh, L. Vanduyfhuys, V. Van Speybroeck, M. Waroquier, and P. W. Ayers, *J. Chem. Theory Comput.* **12** (2016), 3894.