Transferable Coarse-Grained Carbohydrate Models with Bayesian Uncertainty Quantification

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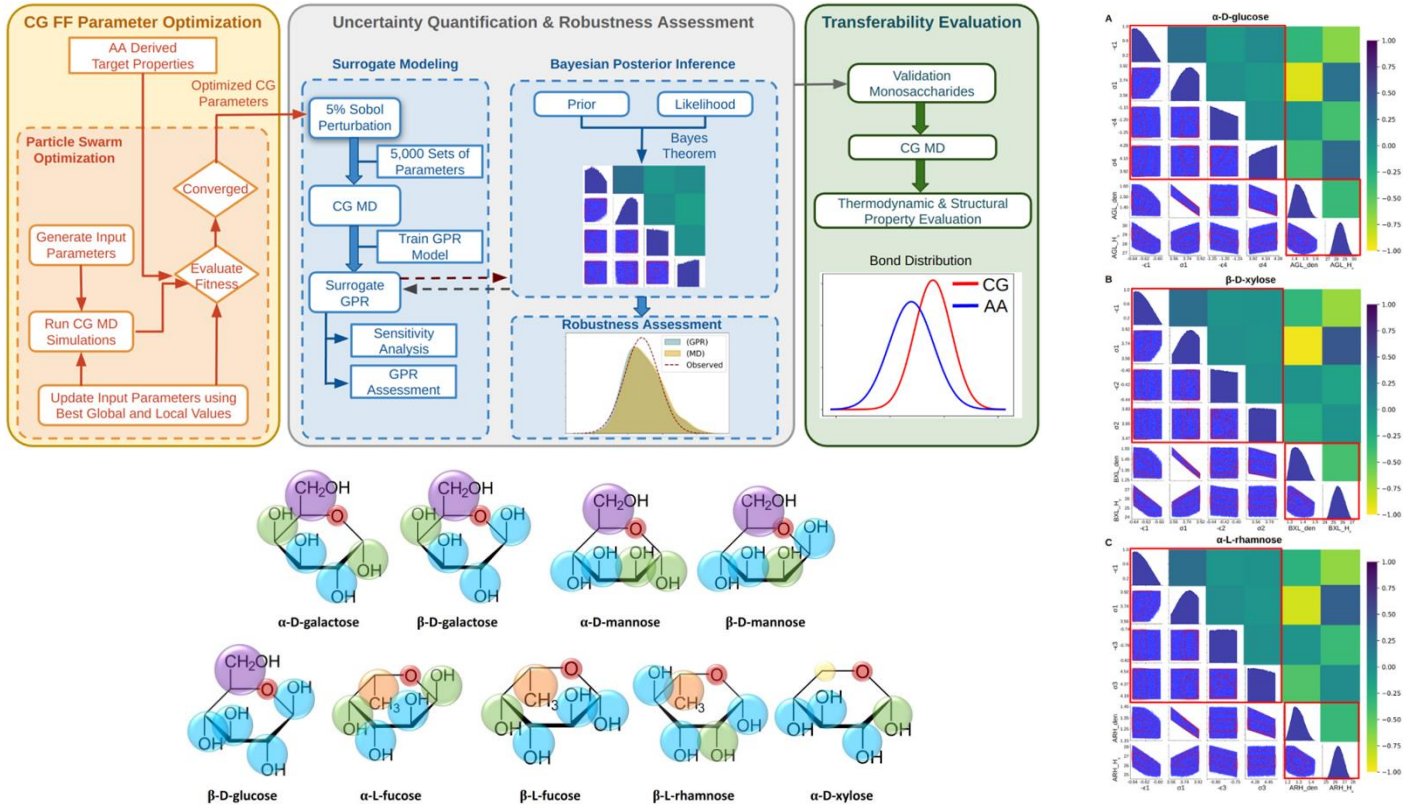
Carbohydrates are structurally diverse molecules whose conformational flexibility makes their molecular behavior difficult to predict. Accurate coarse-grained molecular models enable researchers to investigate larger carbohydrate systems and longer time scales than are accessible with atomistic simulations, providing a foundation for predictive glycomaterials modeling.

A GlycoMIP in-house research team at Virginia Tech, led by Professor Sanket A. Deshmukh, developed a transferable coarse-grained model for pyranose monosaccharides. The team parameterized the model using three representative sugars and subsequently applied the model to nine additional sugars. The coarse-grained model reproduced key thermodynamic and structural properties across all twelve monosaccharides.

The framework combined machine-learning surrogate models with Bayesian uncertainty quantification to identify which force-field parameters were strongly constrained and establish robust ranges over which individual parameters could vary without compromising model accuracy. The model also predicted glass-transition temperatures in good agreement with experimental values for most of the sugars studied, even though this property was not used during parameterization.

The resulting framework enables larger carbohydrate systems to be modeled with explicit measures of confidence and provides a route toward transferable coarse-grained models for oligosaccharides, polysaccharides, and other glycomaterials.



Figures. Left top: Framework for development, uncertainty quantification, and transferability assessment of coarse-grained carbohydrate models. **Left bottom:** Six-bead coarse-grained mapping scheme illustrating how chemically distinct pyranose monosaccharides are represented while preserving key stereochemical features. **Right:** Bayesian posterior distributions showing correlations among force-field parameters and predicted thermodynamic properties.