Activity of Complex Multifunctional Organic Compounds in Common Solvents

Bruce Moller

Juergen Rarey

Deresh Ramjugernath

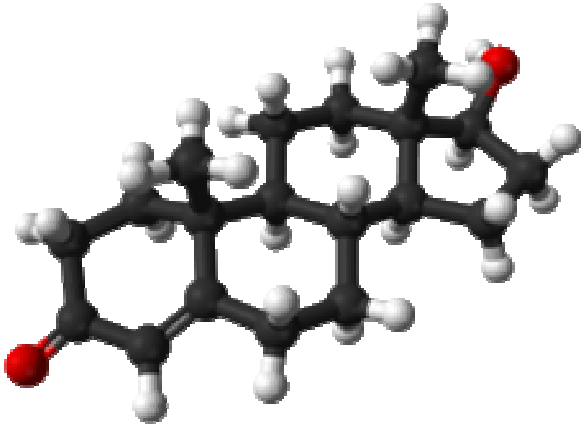
UNIVERSITY OF KWAZULU-NATAL

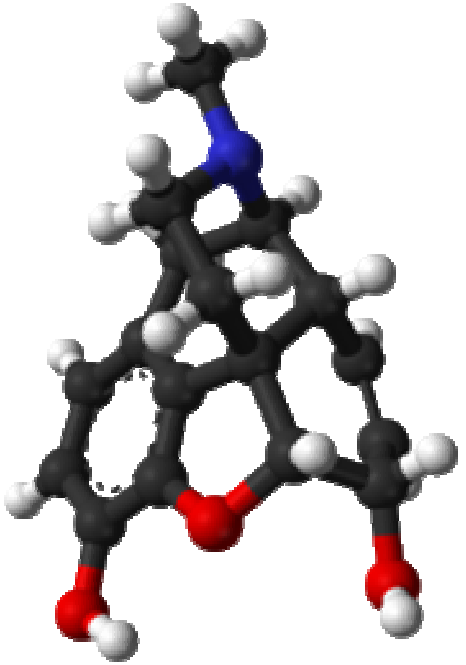
Overview

- Motivation
- Current Methods
- Plan of Action
- Applications
- Future Work

Project Motivation

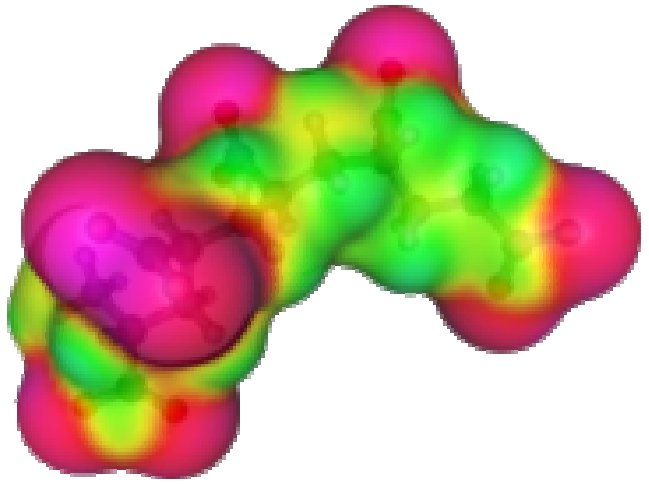
- Solute activity required for:
  - Design of separation equipment
  - Partitioning between compartments
  - Dispensing of drugs
  - …





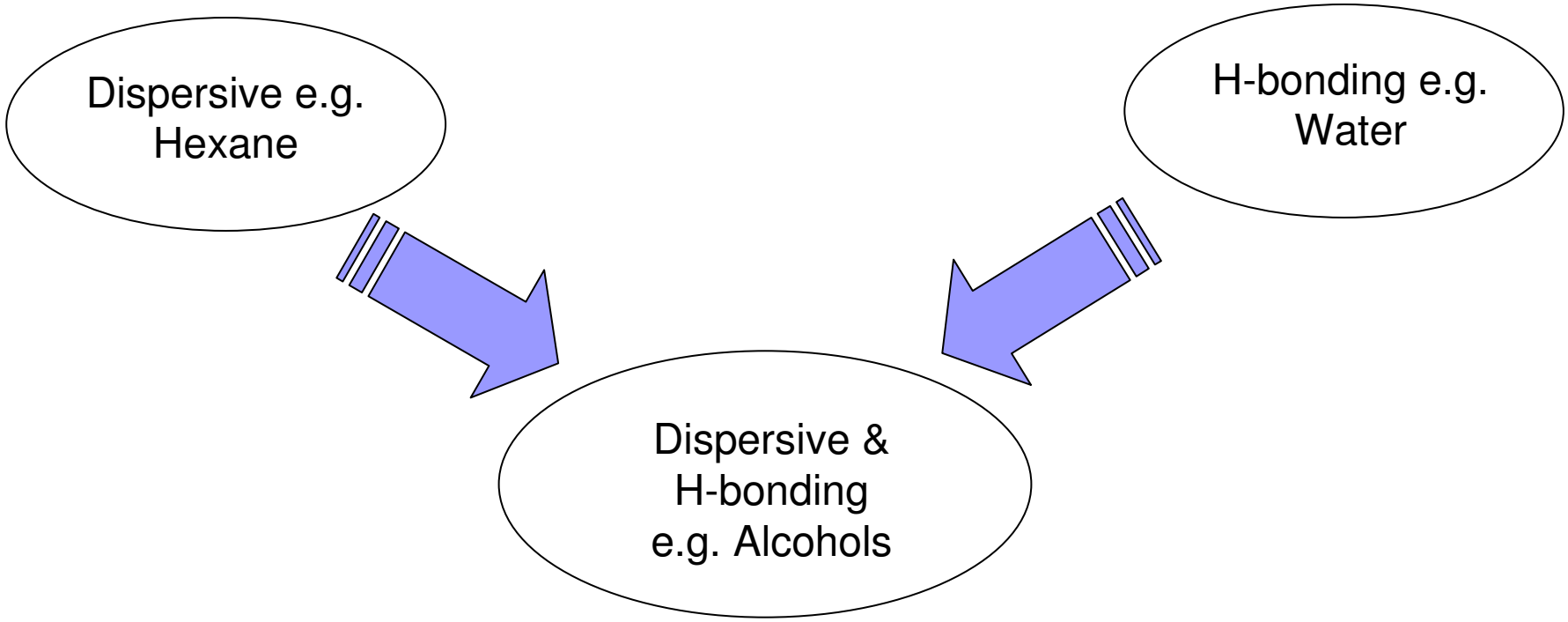
Some Current Methods

- Group contribution methods
  - UNIFAC, Mod. UNIFAC (Do)
- Quantum chemical methods
  - COSMO-RS/SAC
- Molecular simulation
- Problems …



Proposed Plan of Action

- Reference solvents



Simplify the Problem

$$\gamma = f(x, T, P, solvent, solute)$$

- Solvent
  - Reference solvents
- Concentration
  - Solid solubility data mainly of interest
  - Infinite dilution (x < 0.01)
- Pressure
  - Small at low to moderate pressures
- Temperature
  - Non-trivial
  - 298 K

Simplify the Problem

$$\gamma^{\infty}_{298K,solvent} = f(solute)$$

- Pure component property

$$\ln \gamma^{\infty}_{\text{solute in solvent}} = \sum_i v_i C_i + \frac{1}{2}\sum_i \sum_j \frac{GI_{i-j}}{n(m)}$$

Group Contributions

Group Interactions

v_i – group frequency

C_i - group contribution

GI – interaction contribution

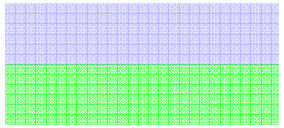
n – number of non-H atoms

m – number of interaction groups

- Trained to data for a single solvent

Available Data

- Most frequent solvents in the γ^{∞} DDB
  - Water
  - Others ???



alkane
water

Solvent	No. Solutes
Water	585
Squalane	207
Hexadecane	198
Sulfolane	137
1-Octanol	128
Phthalic acid dinonyl ester	126
Heptane	116
N-Methyl-2-pyrrolidone	115
Octadecane	103
19,24-Dioctadecyldotetracontane	99

Results for Infinite Dilution Activity Coefficients in Water @ 298 K

Name	This Work	UNIFAC*	Mod. UNIFAC*	COSMO-RS(OL)**	COSMO-SAC**
All compounds	7.3 [630]	23.7 [442]	14.9 [396]	23.4 [295]	30.0 [295]

Significantly lower relative mean deviation (%) in $\ln\gamma^{\infty}$

More generally applicable (greater number of compounds)

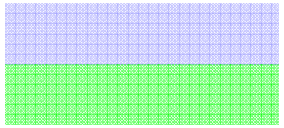
Typically 2nd best, far superior to the other literature methods

* Consortium version 2008

** Based on B3LYP-6-311G(d,p)

Available Data

- Most frequent solvents in the γ^{∞} DDB
  - Water
  - Others ???



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Reduction to a Common Solvent - Hexane

- Combinatorial and residual contribution
- Solution of groups concept

$$\gamma_{1,hexane}^{\infty} = \gamma_{1,hexane}^{R,\infty} \times \gamma_{1,hexane}^{C,\infty}$$

$$\gamma_{1,squalane}^{\infty} = \gamma_{1,squalane}^{R,\infty} \times \gamma_{1,squalane}^{C,\infty}$$

Reduction to a Common Solvent - Hexane

- Combinatorial and residual contribution
- Solution of groups concept

$$\frac{\gamma_{1,hexane}^{\infty}}{\gamma_{1,squalane}^{\infty}} = \frac{\cancel{\gamma_{1,hexane}^{R,\infty}} \times \gamma_{1,hexane}^{C,\infty}}{\cancel{\gamma_{1,squalane}^{R,\infty}} \times \gamma_{1,squalane}^{C,\infty}}$$

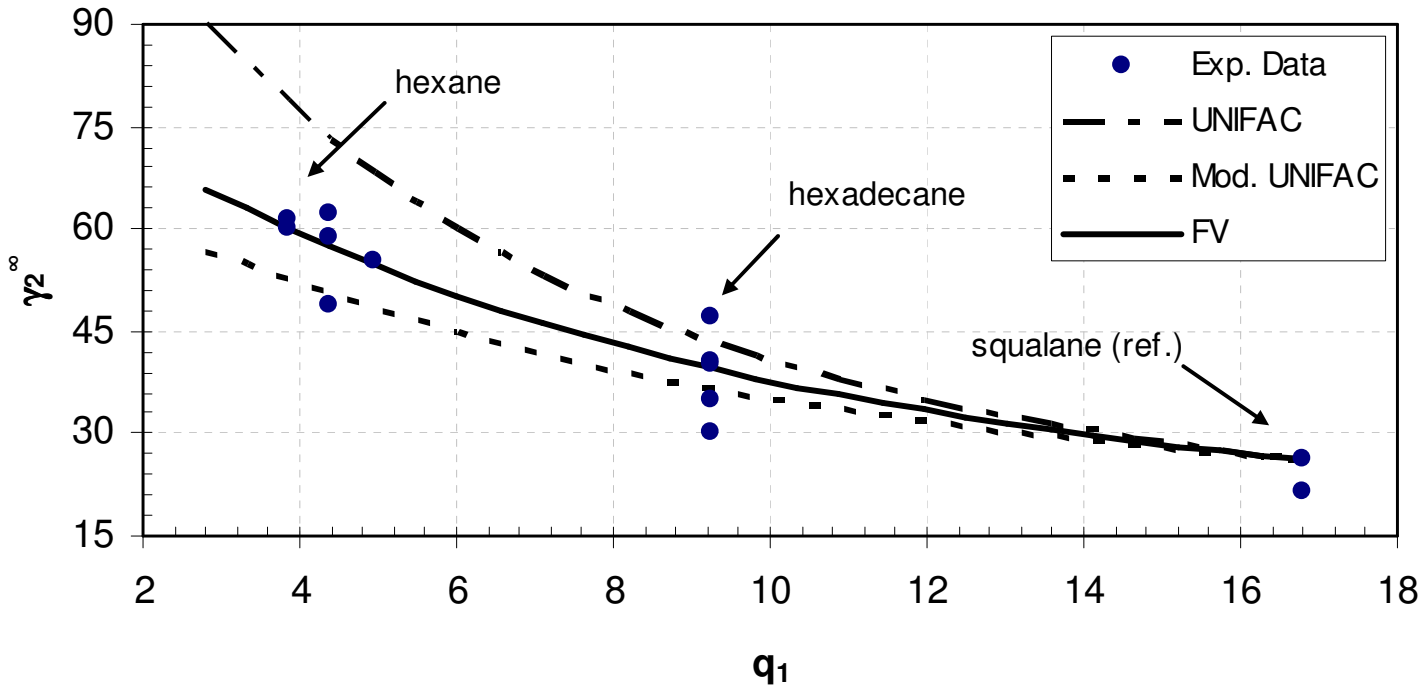
Reduction to a Common Solvent - Hexane

- Combinatorial and residual contribution
- Solution of groups concept

$$\gamma_{1,hexane}^{\infty} = \gamma_{1,reference}^{\infty} \frac{\gamma_{1,hexane}^{C,\infty}}{\gamma_{1,reference}^{C,\infty}}$$

Performance of Combinatorial Expressions

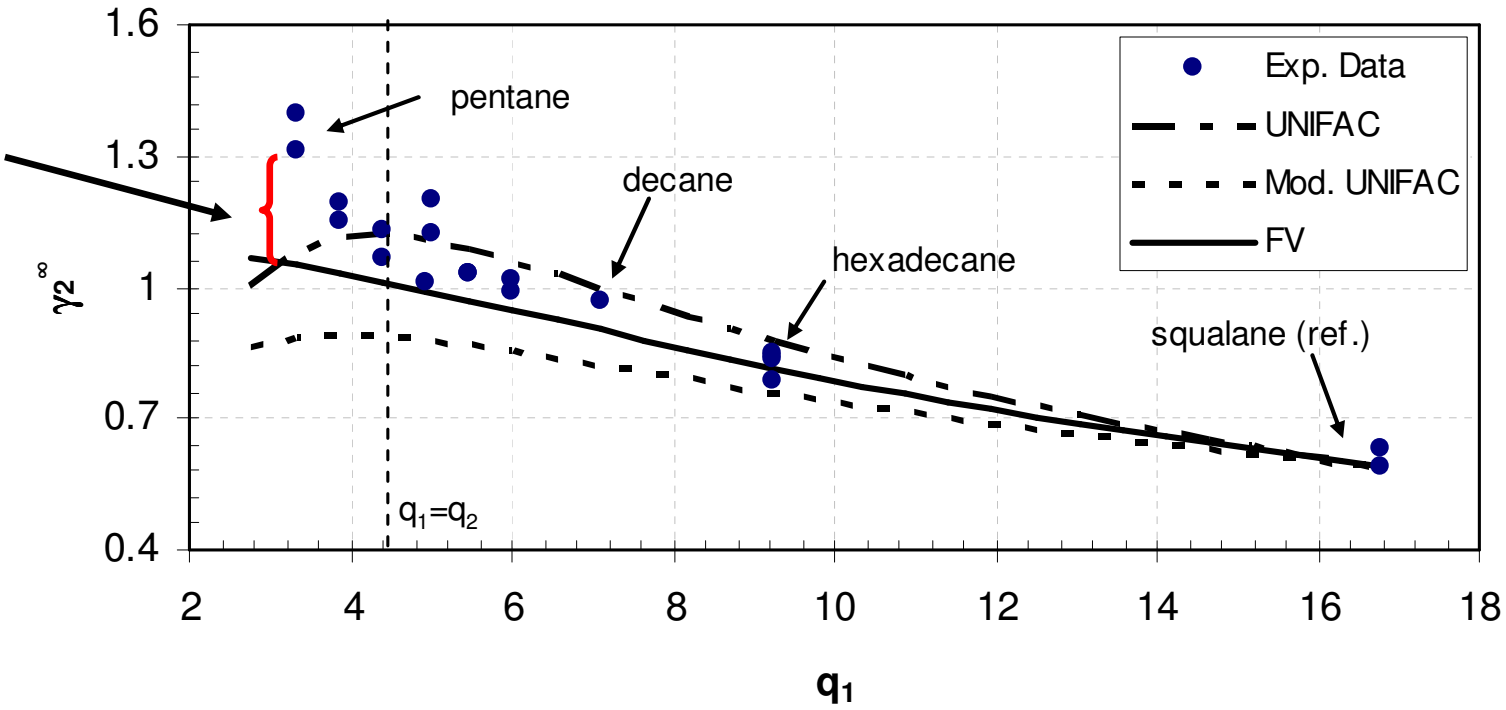
- Ethanol (2) in alkanes (1) …



Performance of Combinatorial Expressions

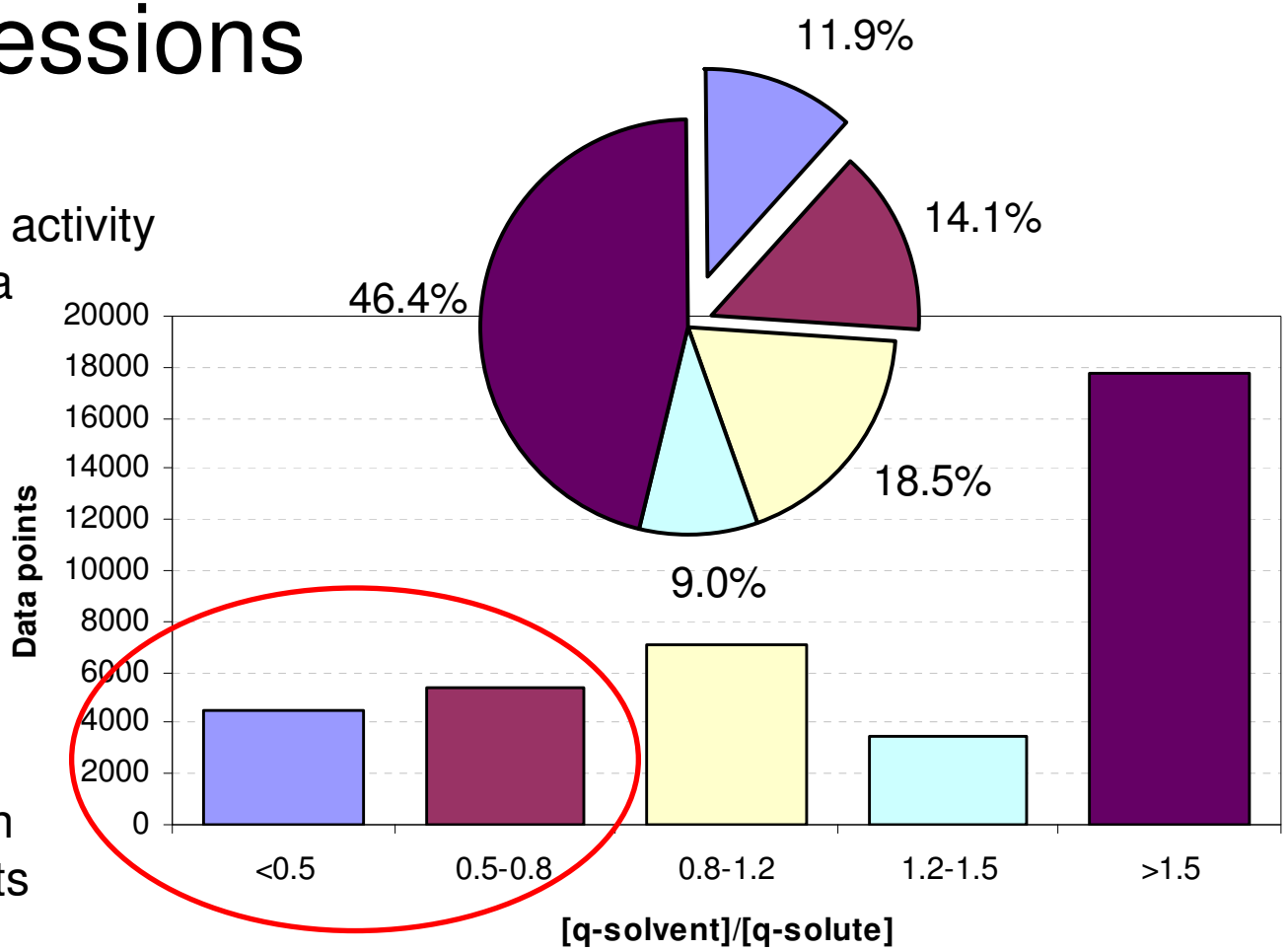
- Ethylcyclohexane (2) in alkanes (1) …

Error starts to become noticeable when $q_1/q_2 < 0.8$



Performance of Combinatorial Expressions

Infinite dilution activity coefficient data



Big solutes in small solvents

New Combinatorial Expression

- Modified the FV expression as follows:

$$\gamma_2^{C,\infty} = \exp\left(1 - \frac{V'^{FV}_2}{V'^{FV}_1} + \ln\left(\frac{V_2^{FV}}{V_1^{FV}}\right) - 5q_2\left(1 - \frac{r_2/r_1}{q_2/q_1} + \ln\left(\frac{r_2/r_1}{q_2/q_1}\right)\right)\right)$$

$$V'^{FV}_i = (V_i)^{2/3} - (V_i^*)^{2/3}$$

V_i – Molar volume (cm^3/mol)

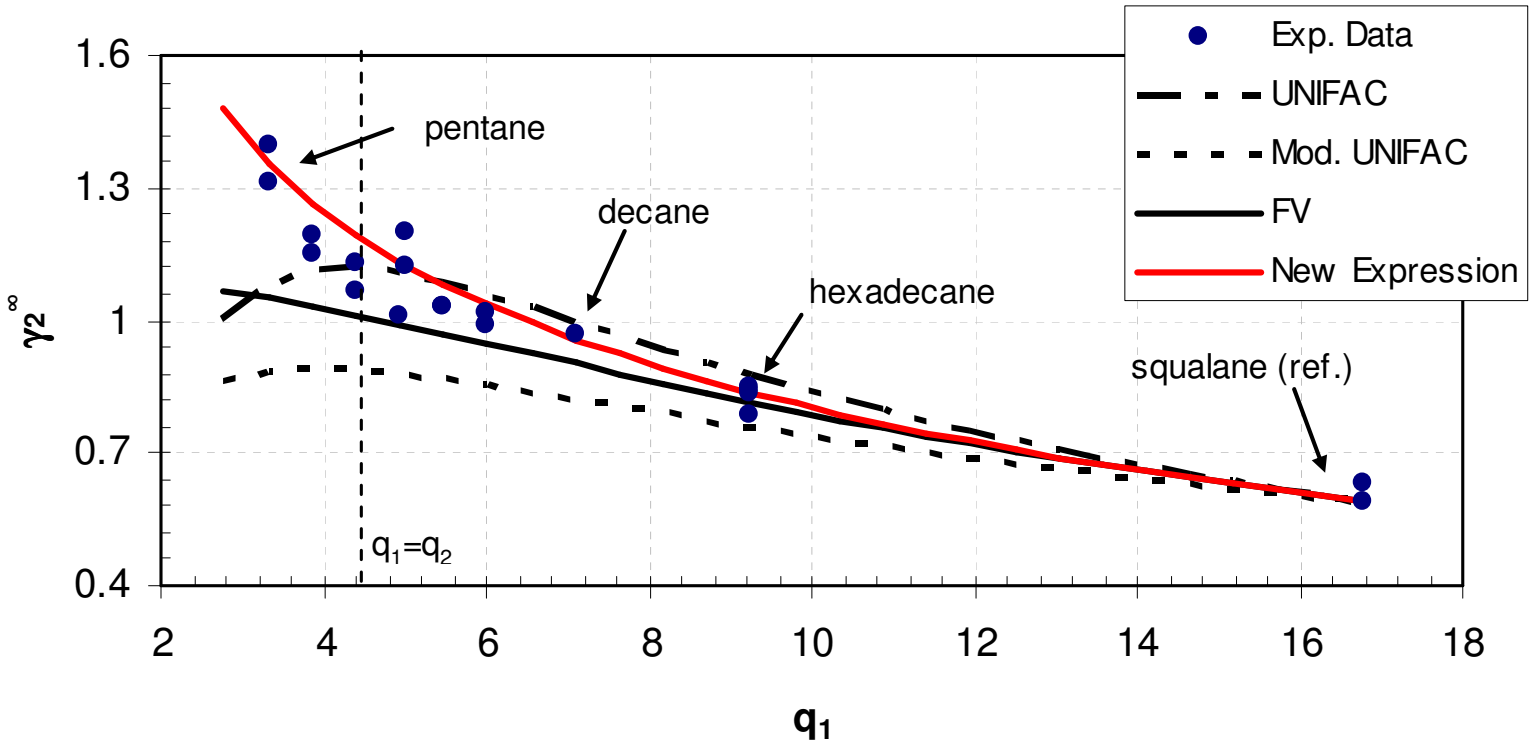
V_i^* - van der Waals Volume (cm^3/mol)

q_i – UNIQUAC surface area

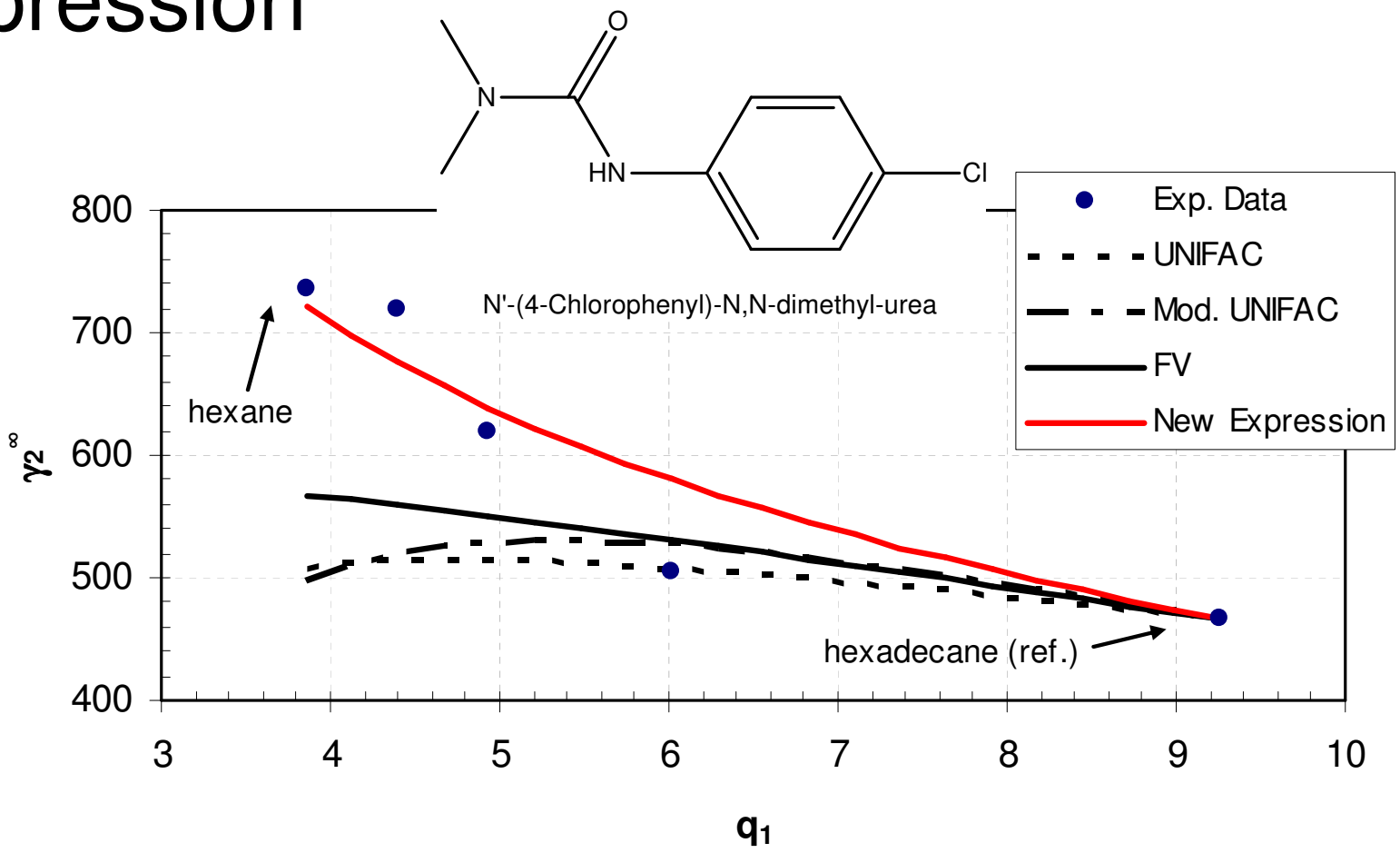
r_i – UNIQUAC volume

Performance of the New Combinatorial Expression

- Ethylcyclohexane (2) in alkanes (1) …



Performance of the New Combinatorial Expression



Results for Infinite Dilution Activity Coefficients in Hexane

Name	This Work	UNIFAC*	Mod. UNIFAC*	COSMO-RS(OL)**	COSMO-SAC**
All compounds	25.9 [202]	47.6 [176]	37.7 [170]	48.1 [156]	54.5 [156]

Lowest relative mean deviation (%) in $\ln\gamma^{\infty}$

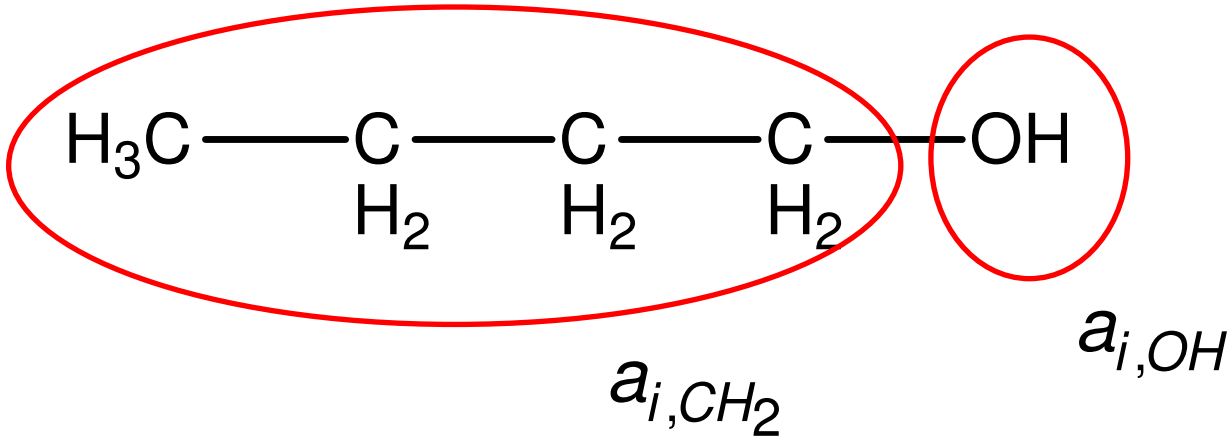
More generally applicable (greater number of compounds)

Typically 2nd best

* Consortium version 2008

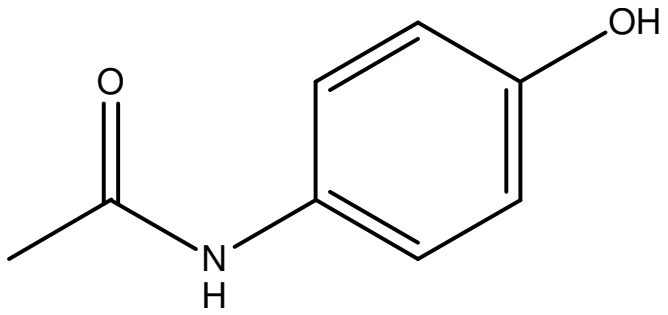
** Based on B3LYP-6-311G(d,p)

Interpolation between Water and Hexane



Applications

Solute

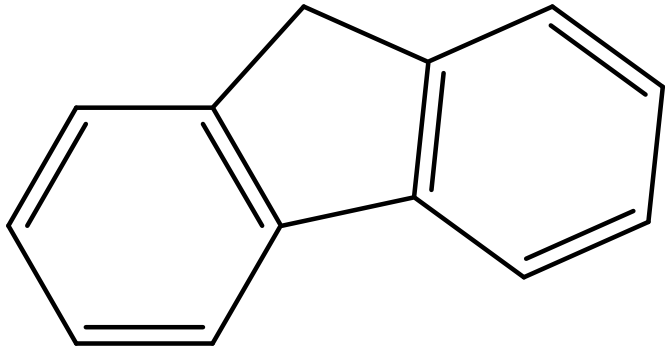


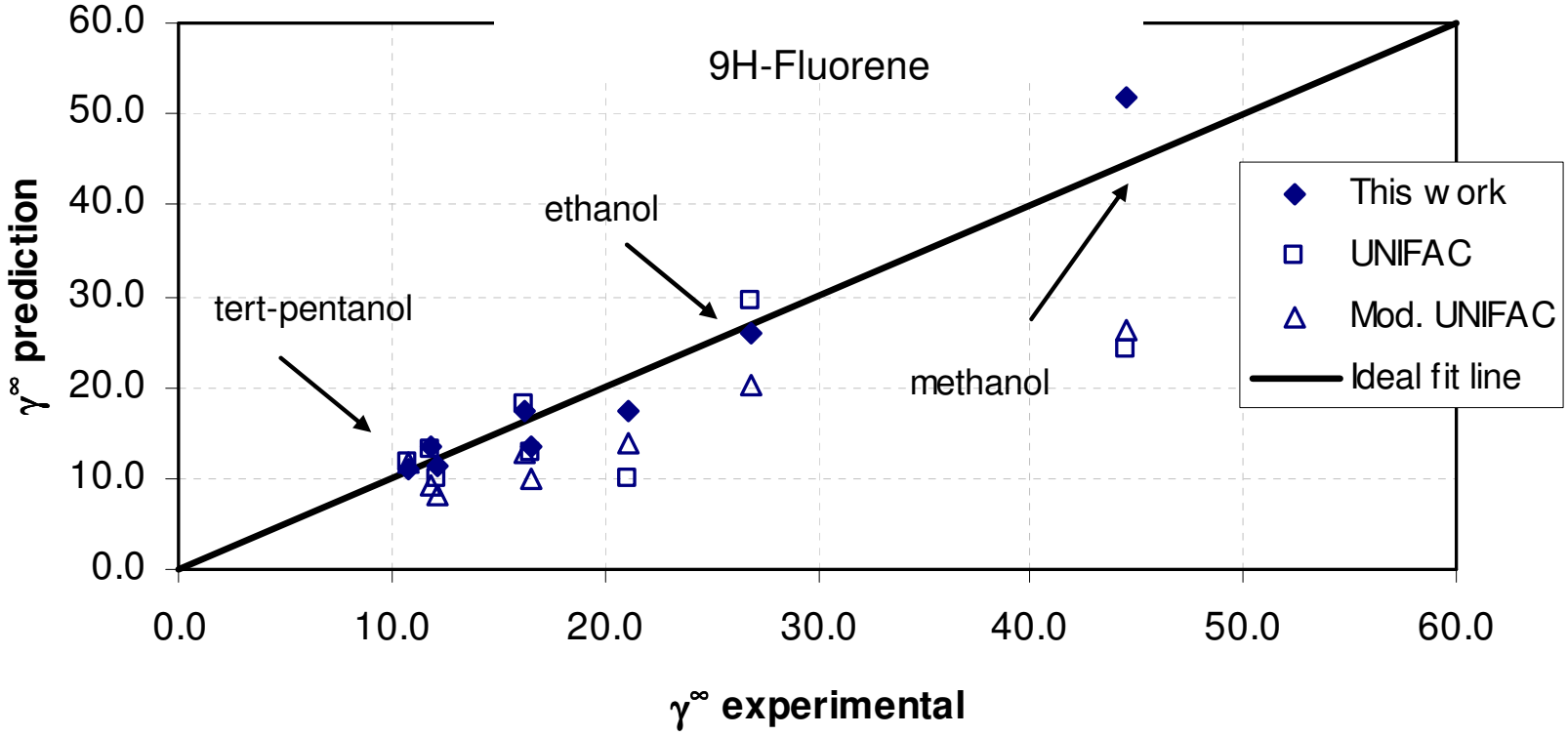
Paracetamol

Solvent	a_{OH}	a_{CH3}	γ^{∞} exp.	γ^{∞} pred.
Water	1.8	0		13
Ethanol	0.296	0.704	16.53	15.8
Hexane	0	2		764

4.5% RMD

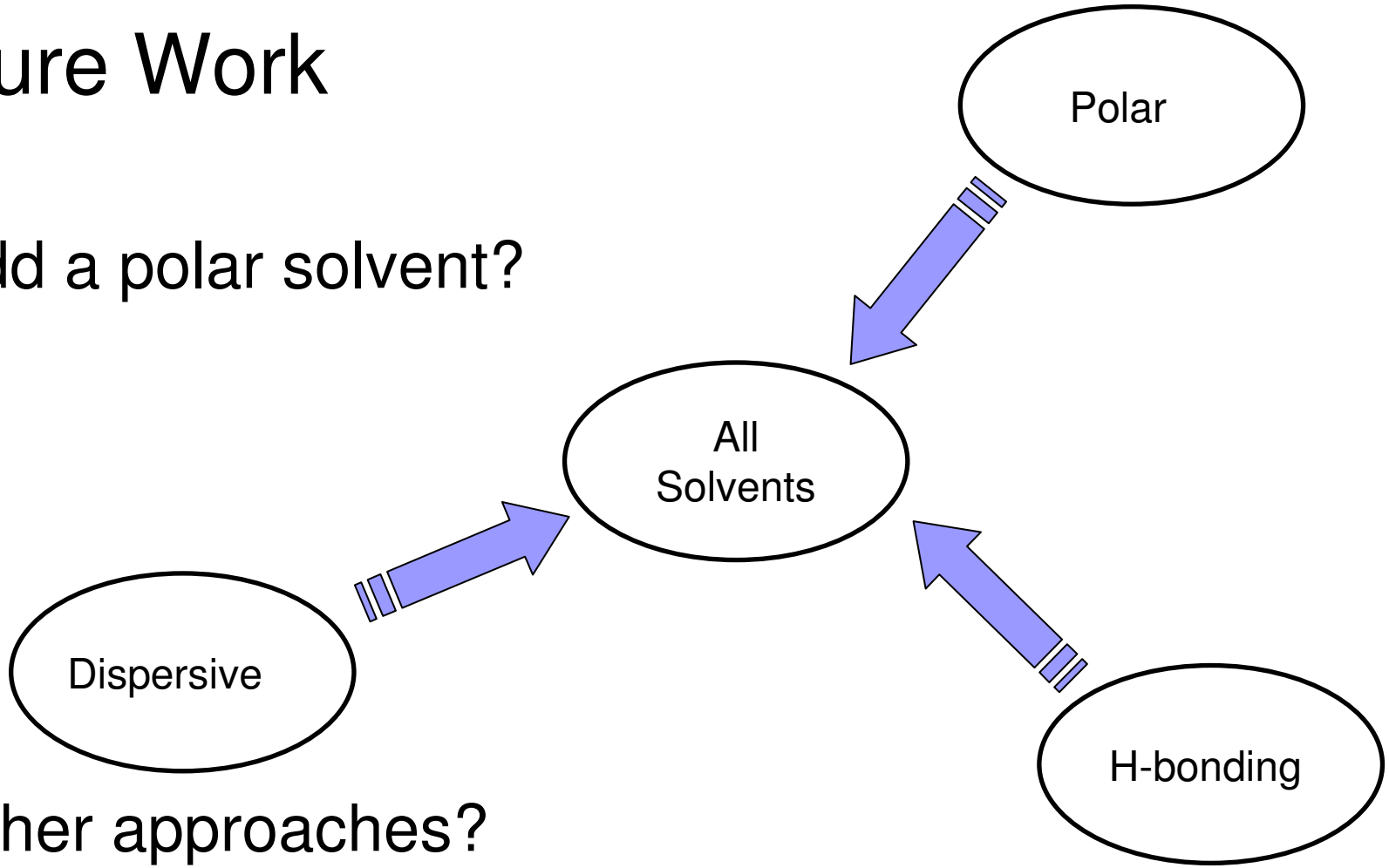
Applications





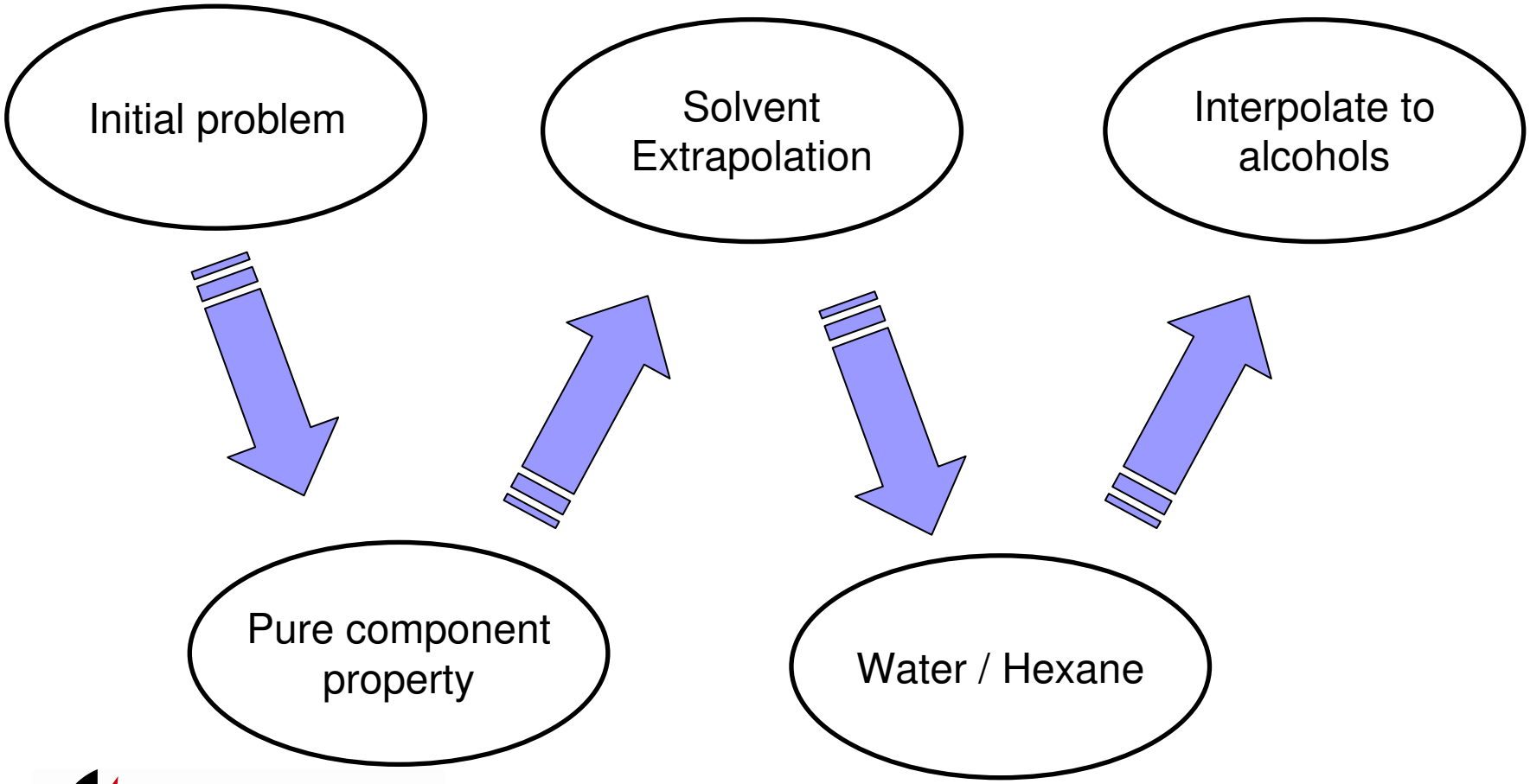
Future Work

- Add a polar solvent?



- Other approaches?

Conclusion


Initial problem
Solvent Extrapolation
Interpolate to alcohols
Pure component property
Water / Hexane

Acknowledgements

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  - Prof. J. Rarey
- Project Leaders:
  - Prof. J. Gmehling
  - Prof. D. Ramjugernath
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  - DDBST GmbH

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