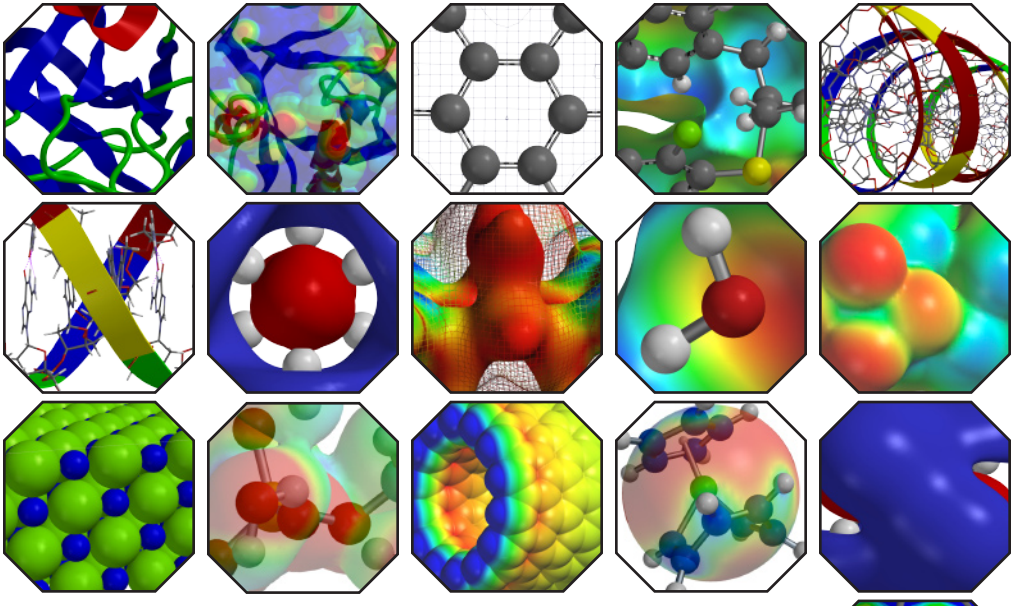
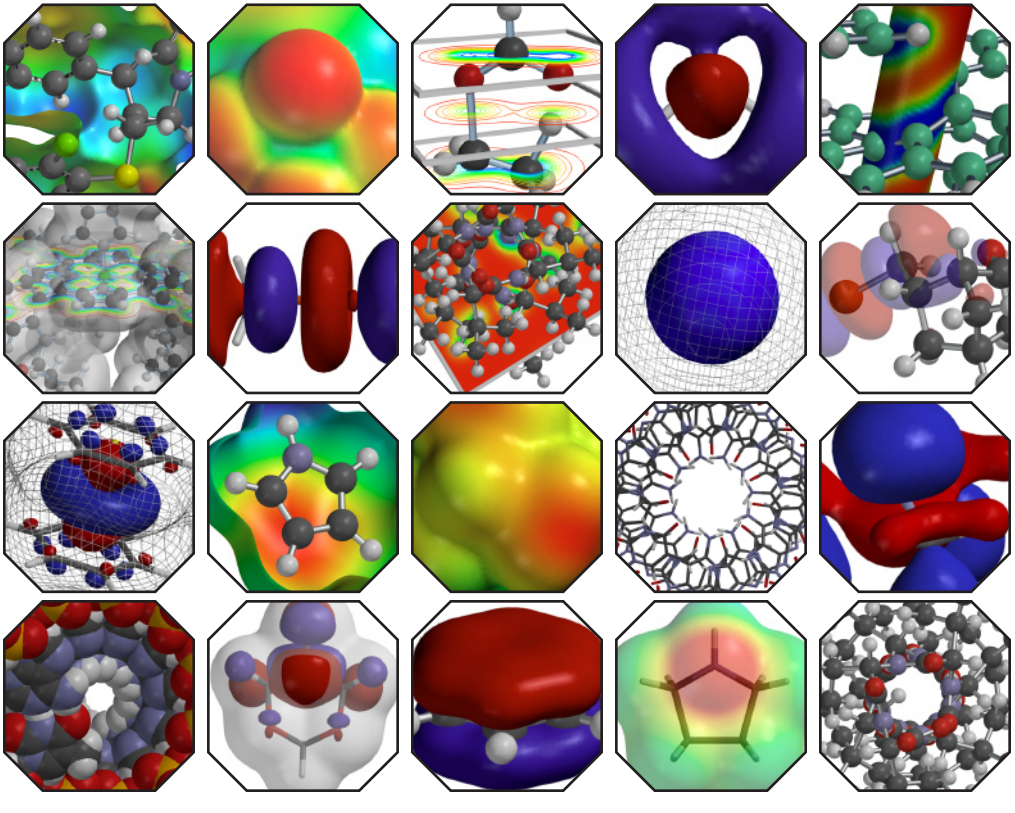


Spartan'24

for Windows, Macintosh and Linux



Spartan'24 is the latest release of the ***Spartan*** molecular modeling application and is a culmination of visualization, computational capabilities, and data interpretation tools, developed and refined since **1991**. New and improved features in ***Spartan'24*** include: extension to the Spartan Spectra & Properties Database (>317,000 molecules and growing), as well as a new SSPD compatibility task, enabling a single submitted calculation so users can easily expand their local SSPD to include molecules of specific interest. This release is also the first to incorporate computational models developed using AI technology. This release introduces a set of 5 unique neural network models, supporting a growing set of applications, including:

IMPROVED CONFORMER ENERGY CALCULATIONS: MOLECULAR MECHANICS

Assessment of the widely used MMFF molecular mechanics approach in conformational searching suggests that resulting conformer energy differences are not very accurate. ***Spartan'24*** employs a neural network model that has been trained on ωB97X-V/6-311+G(2df,2p)[6-311G*] energy calculations from underlying MMFF geometries. In practice, as each MMFF conformer is generated its energy is corrected with a neural net to obtain a "better" energy. This significantly improves accuracy and reduces the number of conformers that need to be considered with better approaches (in ***Spartan's*** multi-step protocols for conformer distribution and the NMR spectra task).

ESTIMATED DENSITY FUNCTIONAL GEOMETRIES

Spartan'24 provides a neural network routine trained to more than 6 milion energy and force calculation from ω**B97X-D/6-31G*** for molecules ranging from 200-600 AMU. Results return several orders of magnitues faster than the underlying quantum chemical model and assessment suggests a high level of agreement. This routine is *also* available for use within the multi-step NMR Spectrum task and utilized in conformational searching.

IMPROVED CONFORMER ENERGY CALCULATIONS: BOLTZMANN WEIGHTS

The penultimate and most costly step in the ***Spartan's*** multi-step protocols for conformer searching and for calculating the NMR spectrum of a flexible molecule involve determining Boltzmann weights for all accessible conformers using the ωB97X-V/6-311+G(2df,2p)//ωB97X-D/6-31G* model. As even simple organic molecules may access hundreds or thousands of conformers, practical time concerns discourage and limit application. ***Spartan'24*** allows replacement of this step with a neural net trained on ωB97X-V/6-311+G(2df,2p) energy calculations from underlying ωB97X-D/6-31G* structures, cutting the overall computation cost for an NMR calculation by more than half.

IMPROVED ENERGY CALCULATIONS

It is generally accepted that better (more complicated) functionals and larger (more flexible) basis sets will lead to significantly improved reaction energies, but at a significant increase in computation cost. Three functionals ωB97X-V, ωB97M-V and ωB97M(2) with 6-311+G(2df,2p) using ωB97X-D/6-31G* geometries, closely approach the results of CCSD(T) calculations, the "gold standard". ***Spartan'24*** incorporates three neural nets that estimate total energies from the above models starting from ωB97X-D/6-31G* geometries with rms errors of only a few kJ/mol. Practically speaking, this extends the size of systems that can be routinely submitted from a few hundred to well over molecular weight 1000 amu.

MULTI-STEP WORKFLOWS

Collectively, the machine learning models are available in most of ***Spartan'24***'s available computational tasks, including: **Energy**, **Equilibrium Geometry**, **Equilibrium Conformer**, **Conformer Distribution**, and the Boltzmann Weighted **NMR Spectrum** task[1]. In particular, the multi-step conformational searching components are available at orders of magnitude faster than the same tasks run with pure quantum chemical models.

TRAINING DATA

SpookyNet[2] has been used to generate the initial five neural networks. Data sets comprise ≈150k molecules with ≈1.8 million conformers obtained from **ωB97X-V/6-311+G(2df,2p)[6-311G*]//MMFF** calculations for the MMFF correction neural net. Collections of ≈120,000 molecules each with equilibrium geometries and 50 distorted geometries (a total of ≈6.1 million structures) obtained from **ωB97X-D/6-31G*** calculations for the estimated **ωB97X-D/6-31G*** geometry neural net, ≈250,000 molecules obtained from **ωB97X-V/6-311+G(2df,2p)//wB97X-D/6-31G*** calculations for the estimated **ωB97X-V/6-311+G(2df,2p)** energy neural net, ≈250,000 molecules obtained from **ωB97M-V/6-311+G(2df,2p)//ωB97X-D/6-31G*** calculations for the estimated **ωB97M-V/6-311+G(2df,2p)** energy neural net, and ≈200,000 molecules obtained from **ωB97M(2)/6-311+G(2df,2p)//ωB97X-D/6-31G*** calculations for the estimated **ωB97M(2)/6-311+G(2df,2p)** energy neural net. Training sets for all three of the final energy neural networks **ωB97X-V/6-311+G(2df,2p)**, **ωB97M-V/6-311+G(2df,2p)**, **ωB97M(2)/6-311+G(2df,2p)** will soon be searchable from within ***Spartan*** from the **Databases** dialog (searches available via substructure, formula, isomer, molecular weight, and name).

1. *J. Nat. Prod.* **2019**, 82 8, 2299-2306.
2. *Nat. Commun.* **2021**, 12(1), 1-14.

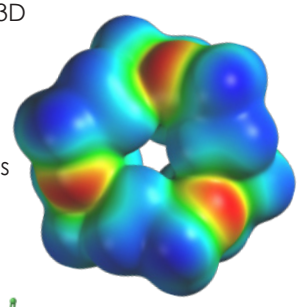
SPARTAN'24 FEATURE SET

GRAPHICAL INTERFACE



Sketch organic, inorganic, organometallic molecules in 2D and automatically convert to 3D structures. Groups, rings and ligands templates are available

Build organic, inorganic and organometallic molecules, peptides and nucleotides, and systematically substituted molecules in 3D



Auto-convert 3D structures to 2D sketches

Link seamlessly to ChemDraw® (Win Only)

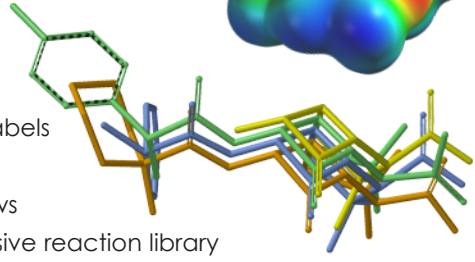
Display/query molecules in a variety of model styles

Display dipole vector, hydrogen bonds, points and planes

Display and customize chemical function descriptors

Display user-defined annotations

New dual (2D/3D) visualization



Align molecules using structure, chemical function descriptors, or atom labels

Align molecules to pharmacophores

Build transition states using reaction arrows

Generate transition states from an extensive reaction library

Generate lists of regio and stereoisomers and lists of tautomers

Generate and display molecular orbitals, electron densities, spin densities electrostatic potentials, electrostatic potential maps, orbital maps, and local ionization potential maps

Optionally silhouette mesh and transparent surfaces for improved visualization

Generate and display orbital energy diagrams on-the-fly

Input experimental proton and ^{13}C chemical shifts

Input observed 3-bond HH couplings and 2 and 3-bond CH couplings for superposition onto calculated COSY and HMBC plots

Toggle between default and absolute property ranges for property maps

Display electron density based on % of enclosed electrons

Highlight solvent accessible regions on surfaces and property maps

Display R/S chirality markers, invert chiral centers and absolute chirality

Automated estimated energies from machine learning routines

Integrated reaction energy calculator

Organize data in spreadsheets

Print and save calculated spectra tables as PDF files

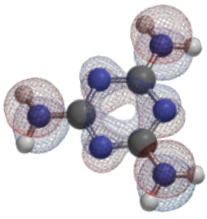
Perform regression analysis and make, save and print 2D or 3D plots

Plot, print, and save calculated and experimental IR, Raman, and UV/vis spectra

Display calculated 1D (proton, ^{13}C, DEPT) and 2D (COSY, HSQC, HMBC) and experimental 1D proton and ^{13}C NMR spectra

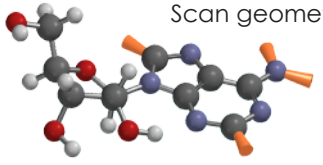
Overlay experimental HMBC and COSY 2D NMR spectra with calculated results

Automatically check and optionally install updates



TASKS

Calculate strain energy, total energy and heat of formation
Determine gas-phase equilibrium and transition-state geometries
Determine geometries and IR spectra in the presence of solvent
Identify global minimum; calculate Boltzmann weights to obtain conformer energy distributions
Build libraries of diverse conformers for use in similarity analysis
Perform similarity analysis on the basis of structure or chemical functionality
Scan geometrical coordinates and generate reaction sequences
Calculate reaction and activation energies
Calculate IR, Raman, UV/vis, and NMR spectra
Determine NMR spectra for flexible molecules
Compare calculated and experimental spectra
Search SSPD and NIST experimental database for match to calculated IR spectra
Mine databases of calculated molecular, atomic, and reaction properties



COMPUTATIONAL METHODS

Molecular Mechanics. SYBYL, MMFF94, MMFF(aq)

Corrected MMFF (neural network energy)

Semi-Empirical. MNDO, AM1, RM1, PM3 (with transition metal parameters), PM6

Hartree-Fock molecular orbital theory

Density Functional Theory (functionals available from menus):
- GGA functionals: B86PW91, BLYP, BPW91, B97-D2, SOGGA11, PBE-D3, VV10
- GH-GGA functionals: B3LYP, B3LYP-D3, EDF2, B3PW91, B97-3, SOGGA11-X
- RSH-GGA functionals: ωB97X-D, ωB97X-V, ωB97X, CAM-B3LYP, N12-SX, LC-VV10
- mGGA functionals: B97M-V, M06-L, BMK, M11-L, TPSS-D3
- GH-mGGA functionals: M06-2X, M06, M08-HX, M08-SO, MPW1B95
- RSH-mGGA functionals: M11, ωB97M-V, MN12-SX
- DH-RSH-mGGA functionals: ωB97M(2)

Estimated ωB97X-D/6-31G* geometries (neural network structure)

Energies from neural networks trained to ωB97X-D, ωB97M-V, ωB97M(2)

Møller Plesset. MP2, MP3, MP4, and RI-MP2

Wave function based advanced correlated models:

G3(MP2)elect, G3elect, G4elect, QCISD, QCISD(T), CCSD, CCSD(T)

Wave function based advanced correlated methods include CCSD, CCSD(T), OD, OD(T), QCCD, VOD, and VQCCD

Excited-state methods. CIS, CIS(D), RI-CIS(D), QCIS(D), QCISD(T) and TDDFT

Gradients available for CIS, CIS(D) and TDDFT

Thermochemical Recipes. T1, G3(MP2), G3, G4

Basis Sets (available from menus):
- Pople: STO-3G, 3-21G, 6-31G*, 6-31G**, 6-31+G**, 6-311G**, 6-311+G**, 6-311G(2d,p), 6-311+G(2d,p), 6-311+G(2df,2p), 6-311+G(3df,2p); other variations on 6-31G and 6-311G may be specified
- Dunning: cc-pVDZ, aug-cc-pVDZ, cc-pVTZ, aug-cc-pVTZ, cc-pVQZ, aug-cc-pVQZ
- Ahlrichs/Weigend: def2-SV(P), def2-SVPD, def2-TZVP, def2-TZVPPD, def2-QZVP, def2-QZVPPD

Automatic use of pseudopotentials for elements >Kr

Dual basis set approximation available

PROPERTIES AND QSAR DESCRIPTORS

Mulliken, natural, and electrostatic-fit charges
Dipole and higher moments, polarizabilities and hyperpolarizabilities
Enthalpies, entropies and free energies
Solvation energies from C-PCM and a number of Truhlar models
Statistical tools for comparing calculated and experimental ^{1}H and ^{13}C NMR shifts
HOMO, LUMO and SOMO energies
Areas, polar surface areas and volumes based on space-filling models
Areas, accessible areas, polar areas, and volumes based on the electron density
Min/Max of electrostatic potential and Min of local ionization potential
Number of conformers and tautomers
Number of hydrogen bond acceptors and donors

SPECTRA

NMR, IR, Raman and UV/visible spectra may be calculated using a variety of theoretical models including Hartree-Fock and density functional models. IR spectra of an unknown molecule may be searched against the SSPD entries for best match.

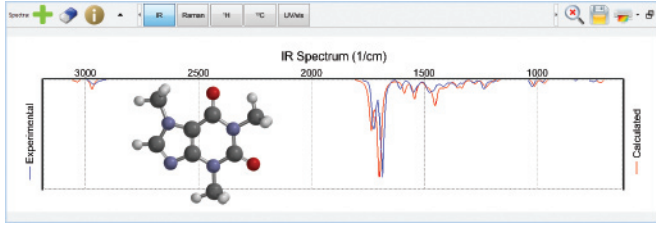
NMR

Corrected, Boltzmann-weighted NMR shifts are available for flexible molecules. ***Spartan'24*** provides neural network routines that *significantly reduce* computational time.

Three-bond HH, CH, and CC coupling constants [using the B3LYP functional with PCJ-0 (PCJ-1 and PCJ-2 basis sets are also available)] allow for ^{1}H, ^{13}C and DEPT 1D spectra and COSY, HSQC and HMBC 2D spectra. Proton spectra may be displayed with or without HH coupling. Observed HH and CH couplings may be inputted to construct "experimental" COSY and HMBC plots which can then be superimposed onto calculated plots.

IR AND RAMAN

Infrared (and Raman) frequencies calculated from ωB97X-D/6-31G*, B3LYP/6-31G* and EDF2/6-31G* density functional models are scaled to account for systematic errors associated with the harmonic approximation. Frequencies and intensities are fit to a Lorentzian function with a line width parameter. Alternatively, scale and line width may be adjusted to best fit a spectrum calculated using any theoretical model to an experimental spectrum.

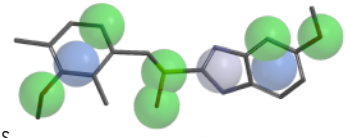


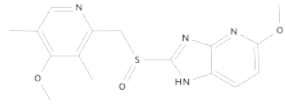
UV/VISIBLE

UV/visible spectra are obtained by explicit calculation of the ground state energies and the low-lying excited states. CIS models are paired with Hartree-Fock models. TDDFT (time dependent density functional) models are paired with density functional models.

ADDITIONAL FEATURES

Multi-core parallel processing for Hartree-Fock, density functional, RI-MP2, and thermochemical recipes.
Automatic processing of groups of molecules
Automatic use of molecular symmetry
View recent documents from File menu
Optimize using constraints and/or frozen atoms
NOEs for conformational searching
Identify tautomers and generate tautomer lists
Import experimental IR, Raman, and NMR spectra





Import structures in InChI, SMILES, CDX, CIF, SKC, SDF, TGF, XYZ, Macromodel, PDB, SYBYL MOL and MOL2 format
Retrieve structures from Cambridge Structural Database and Protein Data Bank
Extract ligands and binding sites from proteins (PDB files)

DATABASES

Spartan Spectra and Properties Database *(SSPD)*® comprises a collection of 317,000 entries, primarily obtained from the ωB97X-D/6-31G* model. Included are the optimized geometry, the energy and a selection of molecular properties, the wave function (allowing on-the-fly generation of graphical surfaces), and the NMR spectrum. The infrared spectrum is provided from EDF2/6-31G*. SSPD entries can replace user-built structures, both collections are searchable by substructure, name, formula, and isomer.

Spartan Reaction Database *(SRD)*® will comprise transition states for ≈8,000 reactions searchable by combination of substructure and "reaction arrows" from either 2D sketches or 3D models.

6-311+G(2df,2p) ENERGY DATABASES

SSPD entries now include three highly accurate density functional databases, comprised of ≈250,000 ωB97X-V/6-311+G(2df,2p) and ωB97M-V/6-311+G(2df,2p), and ≈200,000 ωB97M(2)/6-31+G(2df,2p) energies, from underlying ωB97X-D/6-31G* geometries.

CORRECTED MMFF ENERGIES

Access extremely fast ω**B97X-D/6-311+G(2df,2p)[6-311G*]//MMFF** energy approximation for use in conformational energy comparisons from a new machine learning routine.

ESTIMATED DENSITY FUNCTIONAL STRUCTURES

Machine learning routine provides estimated ω**B97X-D/6-31G*** structures from MMFF geometries, at something like 1-2 orders of magnitude faster than structures derived from quantum mechanics.

ESTIMATED QM ENERGIES

Machine learning routines start from ωB97X-D/6-31G* structures and instantly provides estimated ω**B97X-V**, ω**B97M-V**, and ω**B97M(2)** [all trained with the **6-311+G(2df,2p)** basis set] for improved energies at several orders of magnitude faster than they can be calculated from quantum mechanics.

SPARTAN'24 LICENSING*

	Academic	Government	Commercial
Spartan'24* (up to 16 cores)*	$ 1,800	$ 3,600	$ 5,400
Spartan'24* (greater than 16 cores)*	$ 2,700	$ 5,400	$ 8,100

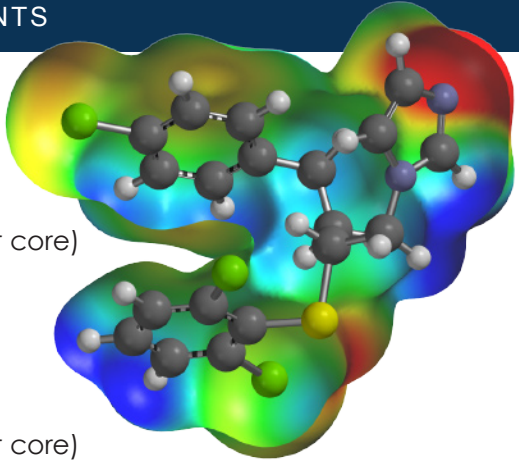
Academic Lab Pricing	***Spartan'24 Parallel Suite***
5 Seat Lab License	$ 7,650
10 Seat Lab License	$ 13,500
20 Seat Lab License	$ 18,000

New licensing includes one year of maintenance, providing for the full SSPD, all minor and major version updates, any necessary license transfers, and priority technical support.

* *Annual campus-wide site license available, contact* ***sales@wavefun.com*** *for pricing.*

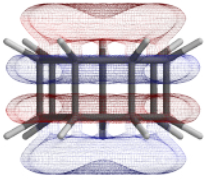
** ***Spartan'24*** *provides parallel processing for select methods and tasks and is available for up to 16 cores (standard), or as a greater than 16 core license (for HPC systems).* ***Spartan*** *also includes access to the* ***Spartan Spectra and Properties Database (SSPD)****, and the ability to act as a computation server for other* ***Spartan*** *licenses or the* ***iSpartan*** *app.*

MINIMUM SYSTEM REQUIREMENTS



WINDOWS
- Intel or AMD (64-bit only)
- Windows 10 or 11
- 128 GB disk space or higher (SSD recommended)
- 4 GB of RAM (at least 2GB RAM per core)

MACINTOSH
- Intel or M1 chips (only)
- OS X 10.12 (Sierra) - 14.X (Sonoma)
- 128 GB disk space or higher (SSD recommended)
- 4 GB RAM (at least 2GB of RAM per core)



LINUX
- Modern Intel or AMD Processors (64-bit only)
- Linux RHEL 8, CentOS 8, Ubuntu 20.04 LTS
- 128 GB disk space or higher (SSD recommended)
- 4 GB RAM (at least 2GB of RAM per core)

Spartan'24
for Windows, Macintosh and Linux
is a collaboration with Q-CHEM

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