TSOpt 2.0: An Overview

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Simulation-Driven Optimization Problems

We are interested in solving optimization problems constrained by differential equations,

$$
\begin{aligned}
\min_{c} \qquad & J(c) = G(u(c,\cdot)) \\
s.t. \qquad & \bar{H}\left(\frac{du}{dt}, u, c\right) = 0\,,
\end{aligned}
$$

given that we have an application package capable of solving the state equation.

Examples:

- Given injector/producer well locations, find well rates that *maximize* revenue, *subject to* the black-oil equations
- Seismic Inversion (TRIP afternoon talks)

TSOpt ("Time Stepping For Optimization")

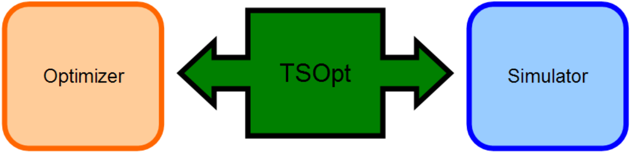
TSOpt is TRIP's "middle-ware" package. TSOpt:

- abstracts commonalities among time-stepping methods
- provides a way for a simulation package to inter-operate with optimization algorithms

Extra Features:

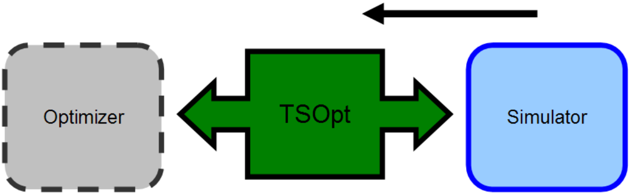
- implements the Adjoint-State method to form gradients
- allows efficient way to verify reference, derivative and adjoint simulation are appropriately related

TSOpt ("Time Stepping For Optimization")



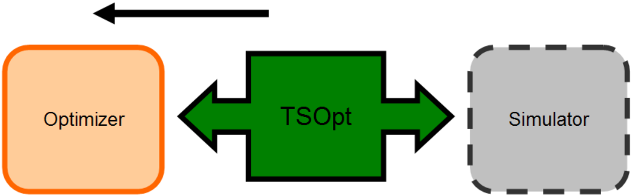
TSOpt ("Time Stepping For Optimization")

$$u^+ = u + \Delta t H(u, c, t)$$



TSOpt ("Time Stepping For Optimization")

$$\nabla J(c), J(c), \ldots$$



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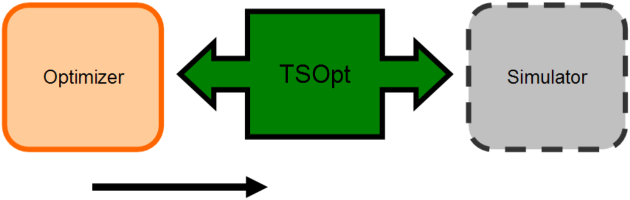
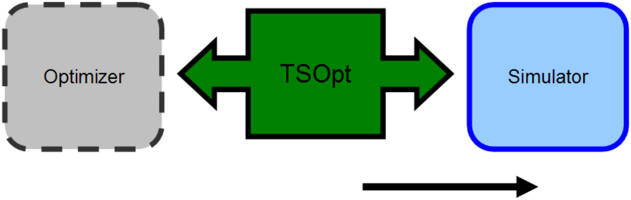


$$s = -B(c)^{-1}\nabla J(c)$$
$$c^{+} = c + \alpha s$$

TSOpt ("Time Stepping For Optimization")



$$c = c^{+}$$

TSOpt and the AS Method

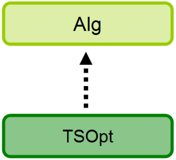
The AS method requires access to the reference simulation state history.

TSOpt implements the following strategies to address this:

- **save all**: save states as you forward simulate, access as needed
  - Cost: **TB**s, for a typical 3D RTM.
- **checkpoint**: rely on forward simulations, *and* use stored simulation states as a starting point for evolution
  - Cost: $O(log(N))$ recomputation, given a special distribution of the states and a small amount of buffers
  - Two flavors: offline and online
- **specialized strategies for specific problems**
  - RTM: only save boundary values

TSOpt and The Alg Framework

TSOpt's components derive from TRIP's `Alg` package, a software framework that can be used to describe any algorithm.



The `Alg` package defines two main objects:

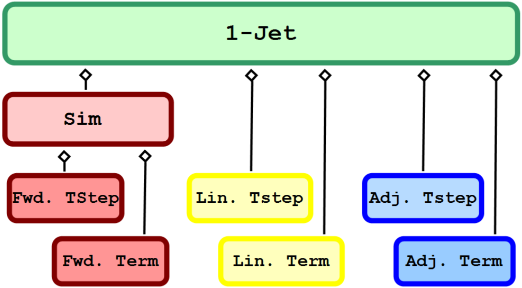
- `Algorithm` objects, which must implement `void run()`
- `Terminator` objects, which must implement `bool query()`

By using these two objects, we may create a variety of algorithms

- composite algorithms: `{ alg1.run(); alg2.run() }`
- iterative algorithms: `while(!term.query()) { alg.run(); }`

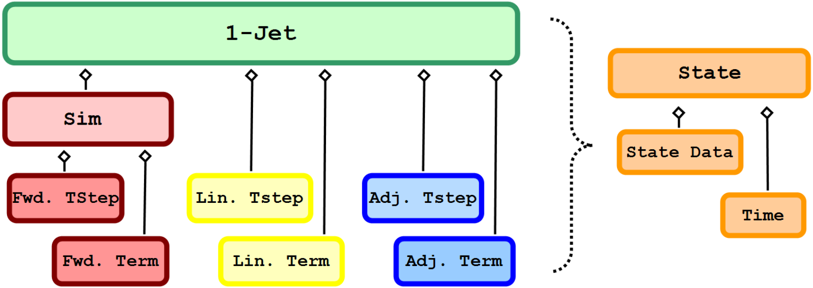
TSOpt's Components

In `TSOpt`, we use `Jet` objects to perform various simulations. Hence, a `Jet` object "holds" information on how to take forward, derivative and adjoint evolution steps.



TSOpt's Components

In `TSOpt`, we use `Jet` objects to perform various simulations. Hence, a `Jet` object "holds" information on how to take forward, derivative and adjoint evolution steps.



All of these classes are templated on a `State` class, which itself holds state data and a time object

Running Simulations in TSOpt

Typically, this is how we create a 1-jet:

```
FwdTimeStep stp(...);                                        // Forward Evolution
FwdDTimeTerm<State> tt(...); tt.setTargetTime(nt);           // Forward Terminator
SaveAllSim<State, containerClass> f(stp,tt);                 // Save all fwd. states

DerTimeStep dstp(...);                                       // Derivative Evolution
FwdDTimeTerm<State> dtt(..); dtt.setTargetTime(nt);          // Derivative Terminator

AdjTimeStep astp(...);                                       // Adjoint Evolution
BwdDTimeTerm<State> att(..); att.setTargetTime(0);           // Adjoint Terminator

StdJet<State> j(f, dstp, dtt, astp, att);                    // Create a jet
j.getAdj().run();                                            // Run adjoint sim.
```

Running Simulations in TSOpt

To use checkpointing in TSOpt, we only change the following line:

```
FwdTimeStep stp(...);                                  // Forward Evolution
FwdDTimeTerm<State> tt(...); tt.setTargetTime(nt);     // Forward Terminator
CPSim<State, containerClass> f(stp,tt, numBuffers);    // Checkpoint

DerTimeStep dstp(...);                                 // Derivative Evolution
FwdDTimeTerm<State> dtt(..); dtt.setTargetTime(nt);    // Derivative Terminator

AdjTimeStep astp(...);                                 // Adjoint Evolution
BwdDTimeTerm<State> att(..); att.setTargetTime(0);     // Adjoint Terminator

StdJet<State> j(f, dstp, dtt, astp, att);              // Create a jet
j.getAdj().run();                                      // Run adjoint sim.
```

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A Unit Test Problem

Consider the following initial value ODE problem:

$$\begin{aligned} u_t &= 1 - u^2 \\ u(0) &= 0.5\,, \qquad\qquad t \in [0, 0.1] \end{aligned}$$

Let's perform the adjoint evolution with the following strategies to handle the reference states:

- save all
- checkpoint

and verify results via the *dot product* test.