



Reflections on 4D Inversion

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Goals of this discussion



- **present**
 - a general formalism
 - a possible simplification
 - issues
- **discussion (brainstorm)**

Specification of model



$$\mathbf{m} = (\mathbf{g} , \mathbf{f} , \mathbf{\kappa})$$

= model

g = geometric + seismic variables (e.g., v_p , v_s , NtG , ρ , ϕ)

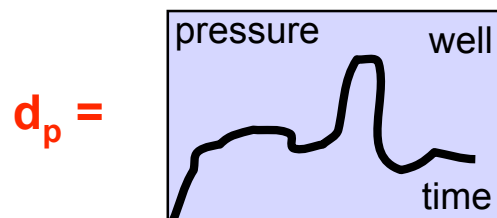
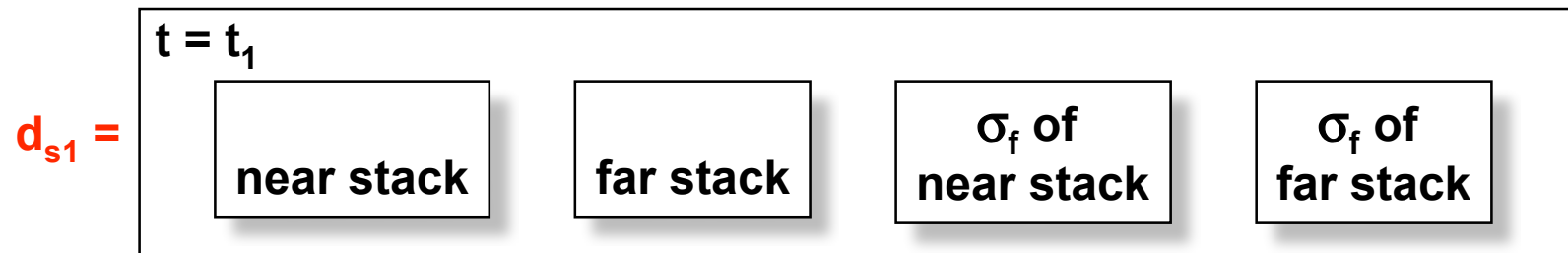
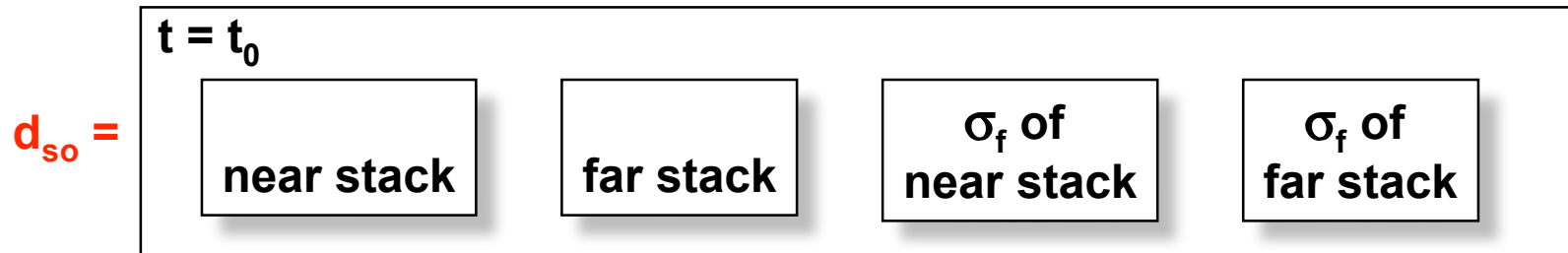
f = fluids in layers

κ = production related properties not well correlated to seismic (e.g., permeability)

Data to match



$$d = (d_{so}, d_{s1}, d_p) \\ = \text{data}$$



Fundamental equation



$$P(m | d) \sim P(m) P(d | m)$$

$P(m)$ = prior probability
= (neural nets, trends, interpolated well logs)

$$P(d | m) = q(s(m) - d)$$

q = noise spectrum

Iterative solution



construct a sequence $\{ P_n(m) \}$ such that

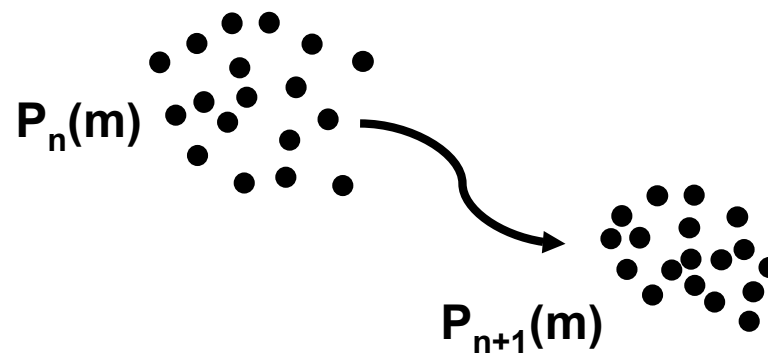
$$P_n(m) \rightarrow P(m | d) \quad \text{as } n \rightarrow \infty,$$

$$P_0(m) = P(m),$$

and

$$P_{n+1}(m) = F(P_n(m))$$

F = conjugate gradient or metropolis



A form for the noise distribution



$$q = q_{s_0}(s_s(g_o, f_o) - d_{s_0}) \quad q_{s_1}(s_s(g_1, f_1) - d_{s_1}) \\ q_f(s_f(g_o, f_o, \kappa) - f_1) \quad q_p(s_p(g_o, f_o, \kappa) - d_p)$$

s_s = seismic forward modeling

s_f and s_p = reservoir simulation

A simplified approach: phased inversion



assume $g_1 = g_o$ (i.e., ignore compaction effects)

and $P(m) = P_1(g_o, f_o, f_1) P_2(\kappa)$

PHASE I: find $\{ (g_o, f_o, f_1)_i \}$ distributed according to

$P_1(g_o, f_o, f_1) q_{s0} q_{s1}$

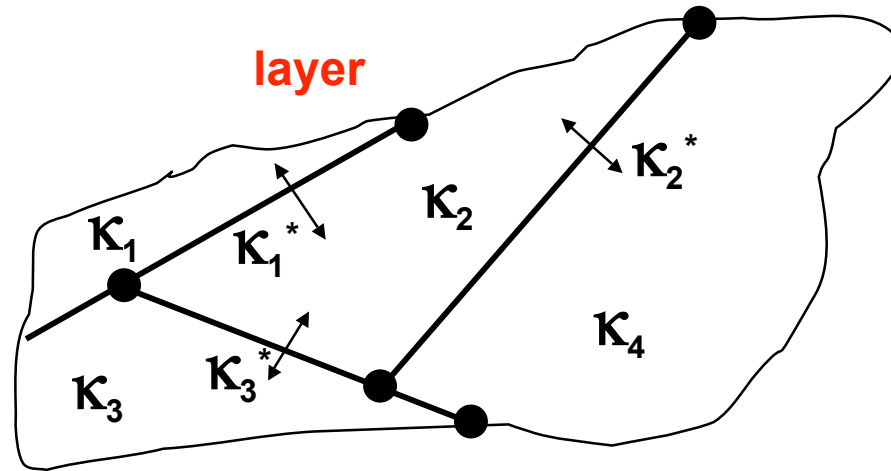
(conventional probabilistic seismic inversion)

PHASE II: find $\{ (i, \kappa)_j \}$ distributed according to

$P_2(\kappa) q_f q_p$

(probabilistic reservoir simulation inversion)

A simplified reservoir model?



κ_i = permeability

κ_i^* = interface permeability

allow κ_i^* , κ_i and endpoints to vary

Major questions



- **should simplified approach be used?**
 - how independent are geophysical and reservoir parameters?
- **how should reservoir simulation be gridded and allowed to vary?**
- **others?**