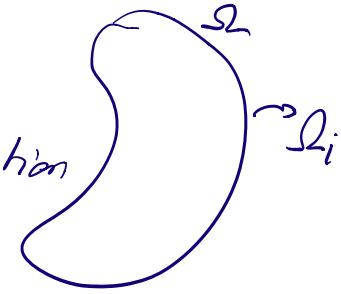
# Numerical methods

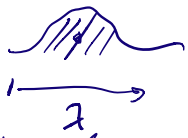
Fully numerical solutions, have 3 characteristics:

1) Divide domain into grid $\Omega_i$
2) $\Omega_i$ defines functional representation
3) define spatial / temporal differential / integral operators $\nabla u \rightarrow \tilde{\nabla} u_i$

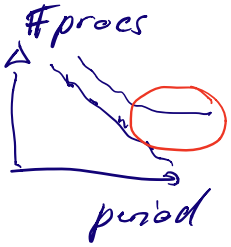



what to look for?

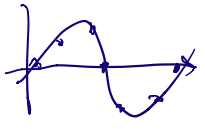
1) fix maximum error at maximum distance
2) model complexity ($\rightarrow$ meshing)

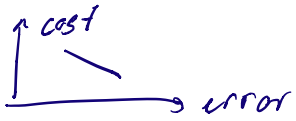



3) practical needs : seismograms, wavefield
4) how many processors to solve solution
   $\rightarrow$ cost-accuracy analysis decides what method is best

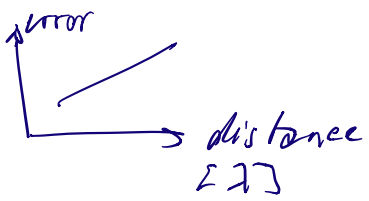



5) optimize input parameter
6) run at higher resolution to validate fix distance





numerical dispersion




Strong vs. weak form of the wave equation:

$$\rho\, \partial_t^2 \underline{u} = \underline{\nabla} \cdot \underline{\underline{T}} \qquad \underline{\text{strong}} \text{ form (FD, PS)}$$

$$\int_\Omega \underline{w} \cdot \rho\, \partial_t^2 \underline{u}\, dV = \int_\Omega \underline{w} \cdot \underline{\nabla} \cdot \underline{\underline{T}}\, dV \qquad \underline{\text{weak}} \text{ form (FEM, FV)}$$

Let's look at

$$\int_\Omega \underline{w} \cdot \underline{\nabla} \cdot \underline{\underline{T}}\, dV = \int_\Omega \underline{w} \cdot \underline{\nabla} \cdot (\underline{\underline{\underline{c}}} : \underline{\nabla} \underline{u})\, dV$$

$$= -\int_\Omega \underline{\nabla} \underline{w} : \underline{\underline{\underline{c}}} : \underline{\nabla} \underline{u}\, dV$$

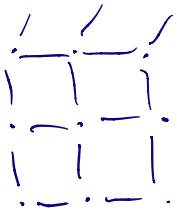
$$+ \int_\Omega \underline{\nabla} \cdot (\underline{w} \cdot \underline{\underline{T}})\, dV$$

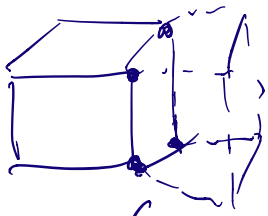
$$= \int_{\partial\Omega} \hat{\underline{n}} \cdot \underline{\underline{T}} \cdot \underline{w}\, dS \overset{!}{=} 0$$

with stress-free boundary condition $\hat{\underline{n}} \cdot \underline{\underline{T}} = 0$ on $\partial\Omega$

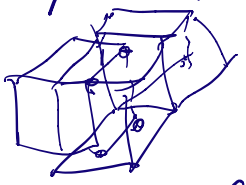
Finite volume methods: $\int_{\Omega_i} \nabla \cdot \underline{f} \, dV = \int_{\partial\Omega} \underline{f} \cdot \hat{n} \, dS$

$\Omega_i$: volume; $\partial\Omega$: surface for each element





conforming mesh



non-conforming mesh

Finite difference (FD) → Finite element (SEM) → Finite volume (DG)

→ increasing (geometrical) flexibility & costs