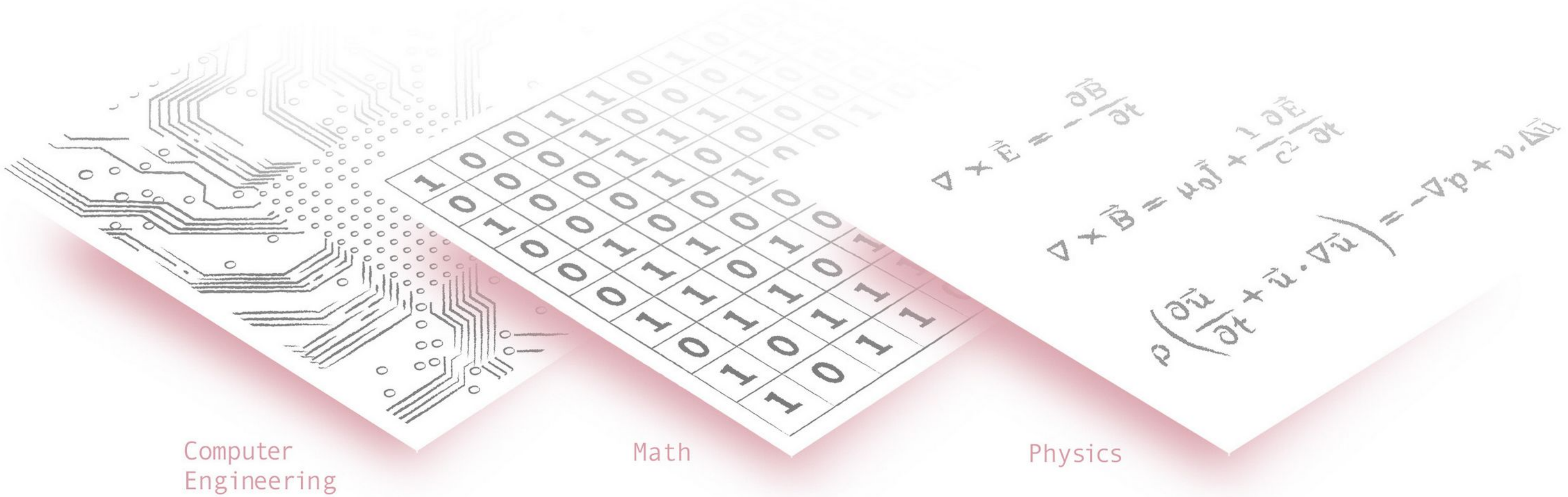
INTRO TO FDTD

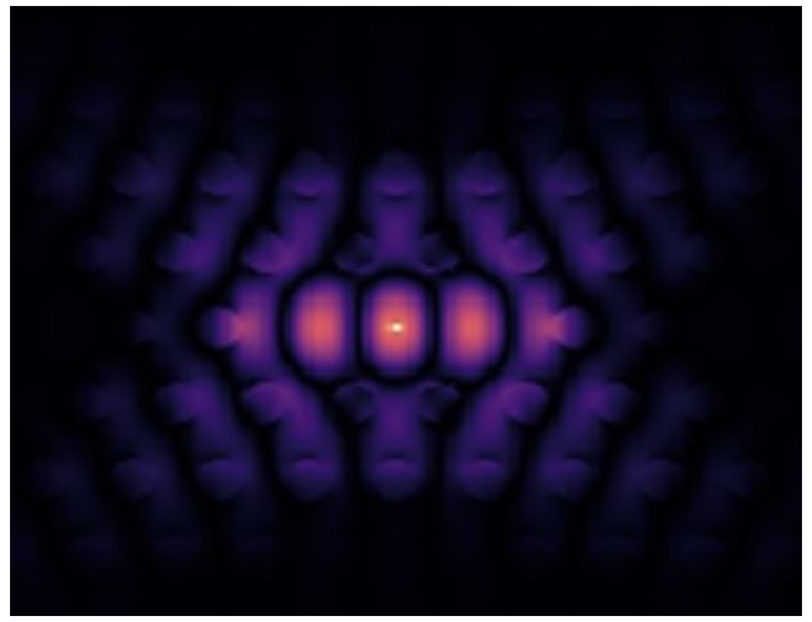
Flexcompute **Inc.**



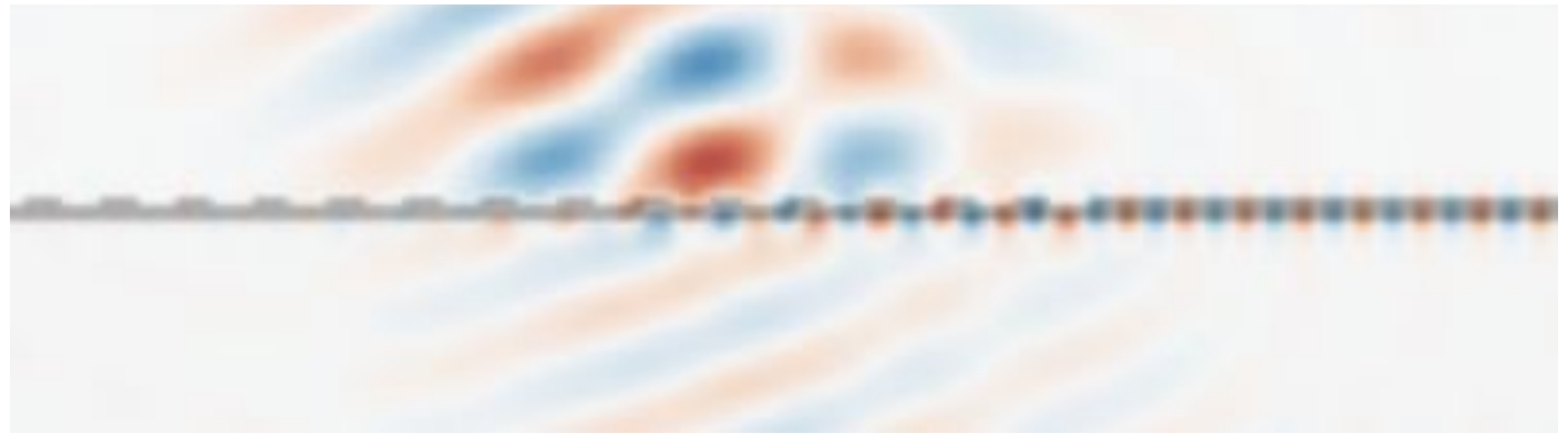
INTRODUCTION

- The Finite-Difference Time-Domain (FDTD) method is a method for simulating interaction of light with structures and materials.
- It is the most widely used and general-purpose method.
- Let's you simulate a wide range of phenomena in photonics.

Photonic crystal cavity

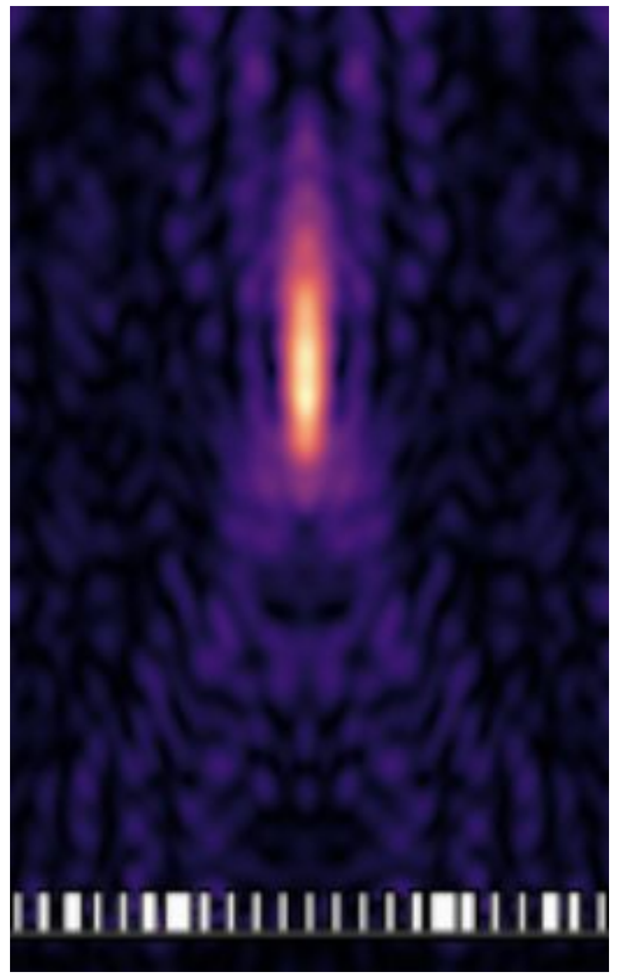


Grating coupler



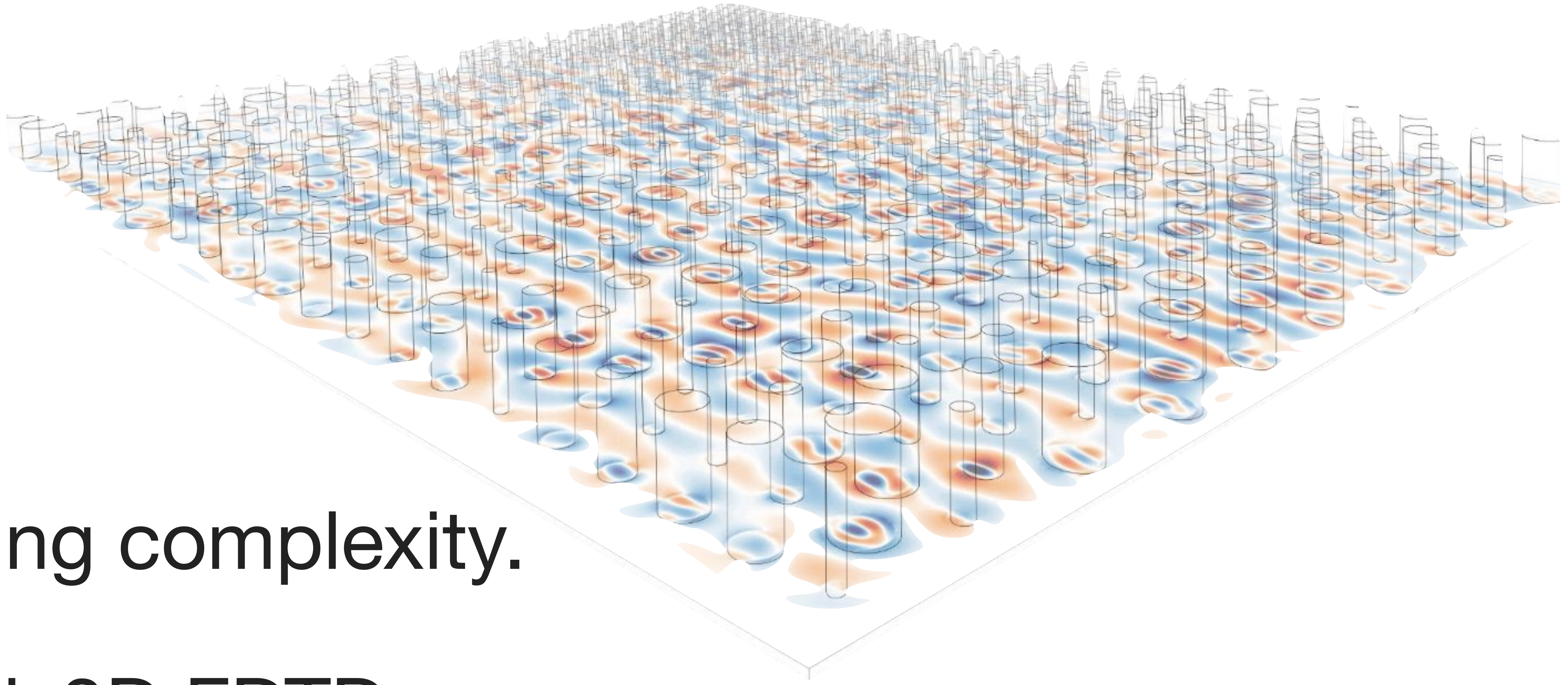
Ring Resonator

Metasurface



COURSE OVERVIEW

- This course will give you a broad understanding of FDTD.
  - What it is used for.
  - How it works (at a high level).
  - How to get started using it.
- The course will use examples in increasing complexity.
- Implementation using Flexcompute’s Tidy3D FDTD solver will accompany examples so you can try them out yourself.



MAXWELL'S EQUATIONS

- In the absence of free charges, electromagnetic phenomena is described by:

$$\nabla \times \vec{E}(\vec{r},t) = -\mu_0 \frac{\partial \vec{H}(\vec{r},t)}{dt} \qquad \nabla \times \vec{H}(\vec{r},t) = \epsilon(\vec{r})\epsilon_0 \frac{\partial \vec{E}(\vec{r},t)}{dt} + \vec{J}(\vec{r},t)$$

$\vec{E}(\vec{r},t)$ and $\vec{H}(\vec{r},t)$ are the electromagnetic fields, from which we can determine our quantities of interest.

$\epsilon(\vec{r})$ describes how the materials are arranged in space, which describe the device being simulated.

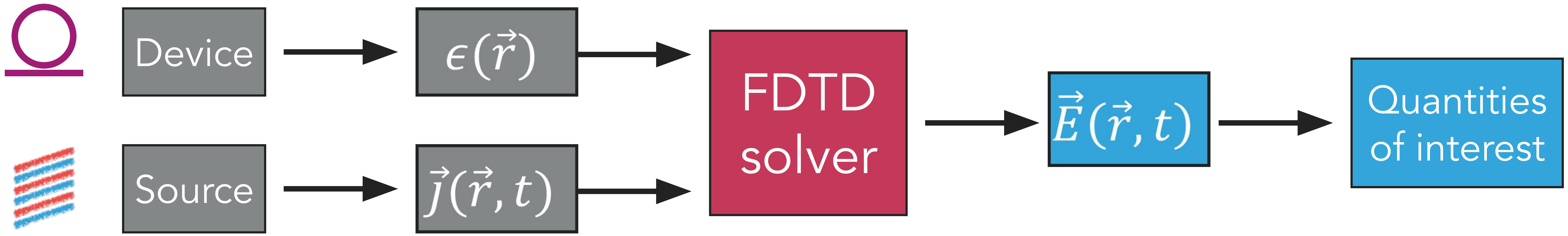
$\vec{J}(\vec{r},t)$ describes electric currents (moving charges), which inject light into the system.

SOLVING MAXWELL'S EQUATIONS

- Goal of FDTD is to solve these equations for $\vec{E}(\vec{r},t)$ and $\vec{H}(\vec{r},t)$ given $\epsilon(\vec{r})$ and $\vec{j}(\vec{r},t)$.

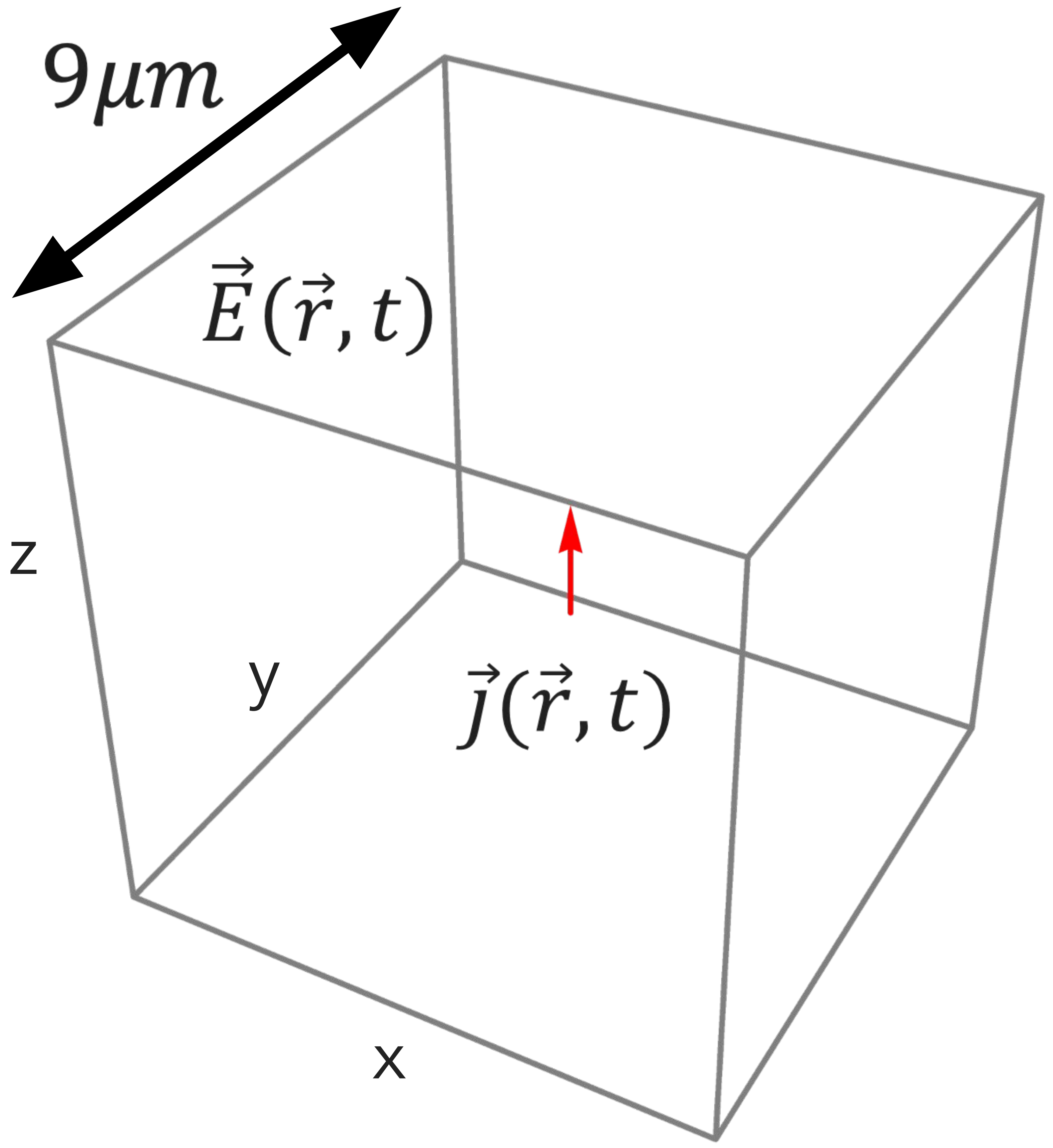
$$\nabla \times \vec{E}(\vec{r},t) = -\mu_0 \frac{\vec{H}(\vec{r},t)}{dt} \qquad \nabla \times \vec{H}(\vec{r},t) = \epsilon(\vec{r})\epsilon_0 \frac{d\vec{E}(\vec{r},t)}{dt} + \vec{j}(\vec{r},t)$$

- Given some device $\epsilon(\vec{r})$ and an incident field or current source $\vec{j}(\vec{r},t)$.



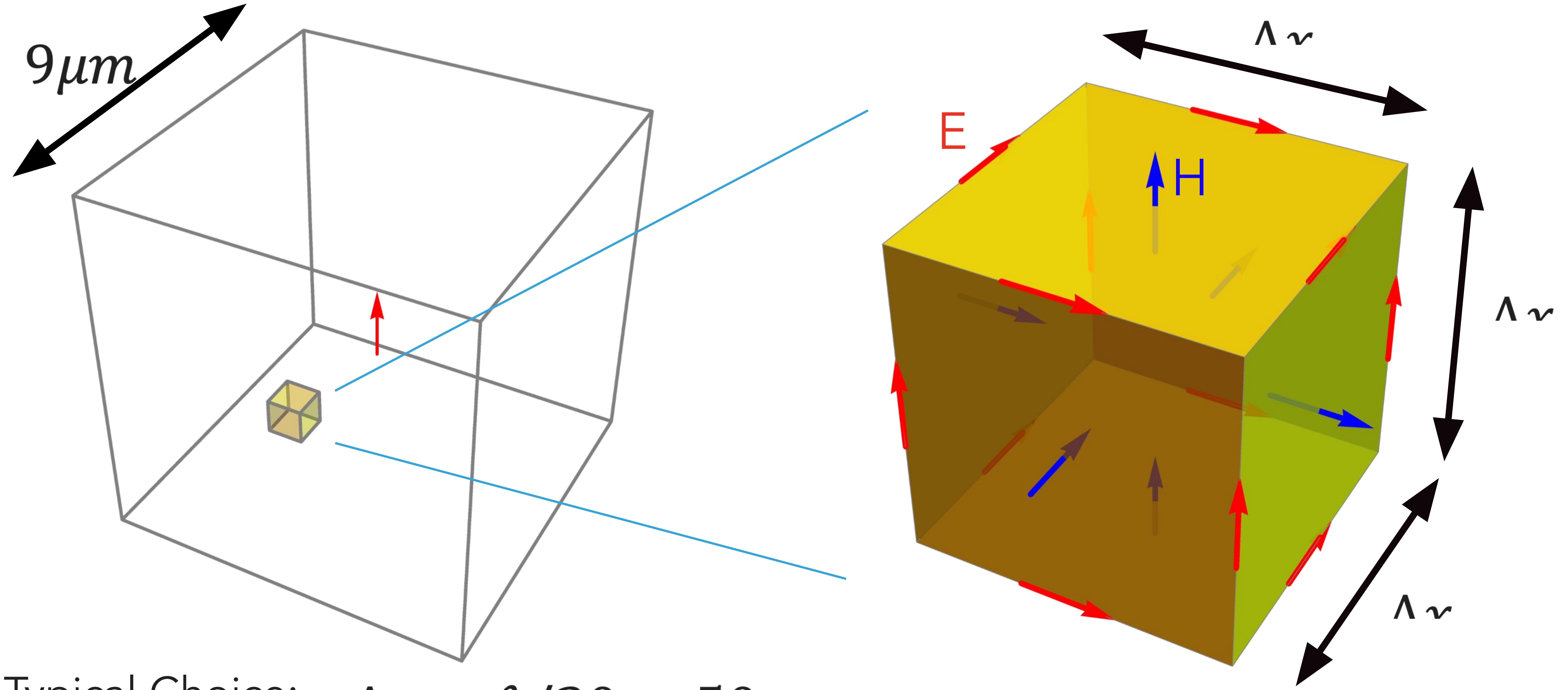
EXAMPLE: DIPOLE IN A VACUUM

- Goal: compute $\vec{E}(\vec{r},t)$ emanating from the source.
- Let's simulate the following setup:
  - Only vacuum ($\epsilon(\vec{r}) = 1$).
  - Dipole source pointing in z direction.
  - $\vec{j}(\vec{r},t) \propto \cos\omega t$.
  - Wavelength $\lambda = 2\pi c/\omega = 1\mu m$.



DISCRETIZATION

Yee Cell

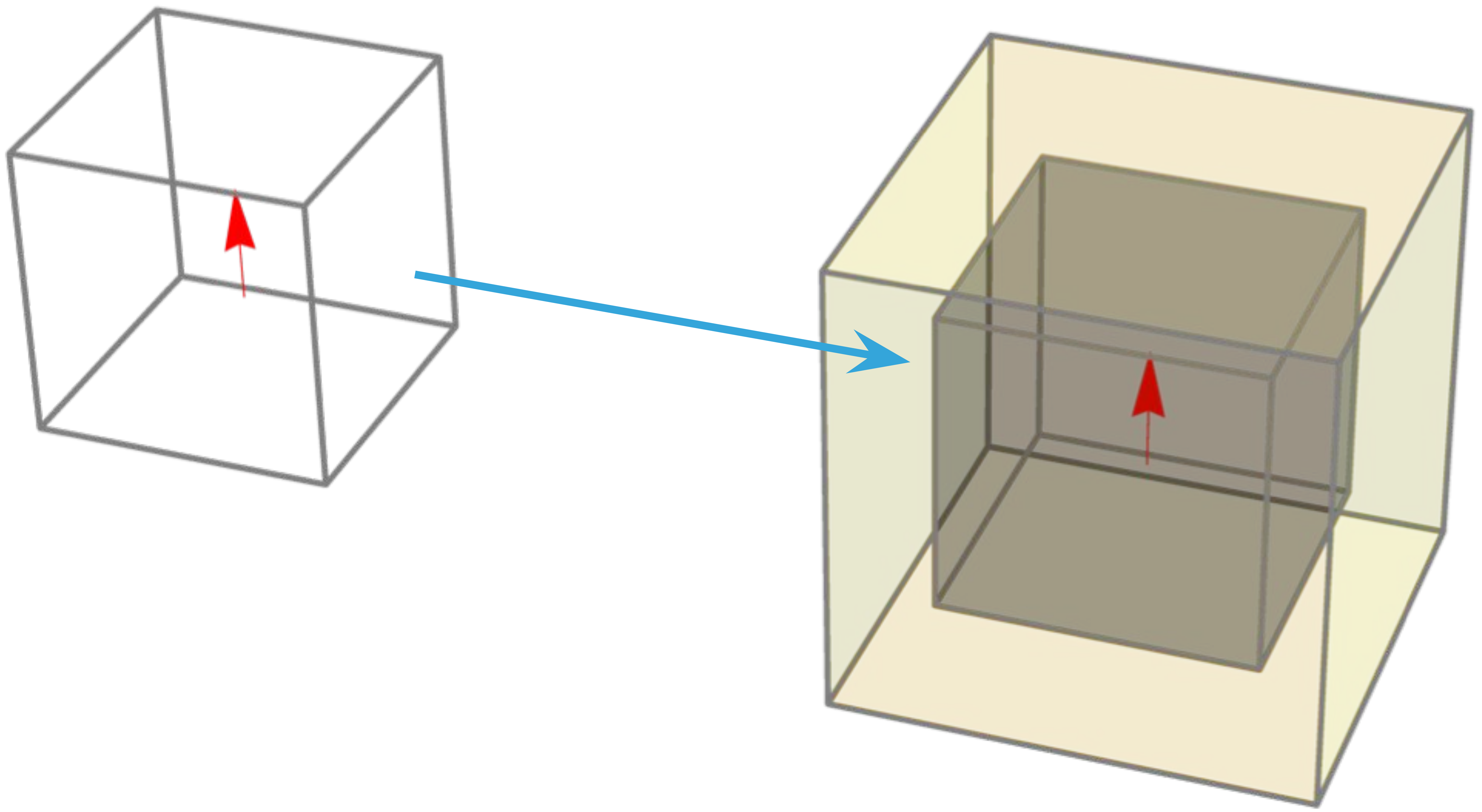


Typical Choice: $\Delta x = \lambda/20 = 50nm$

Here: $\Delta x = \lambda/50 = 20nm$

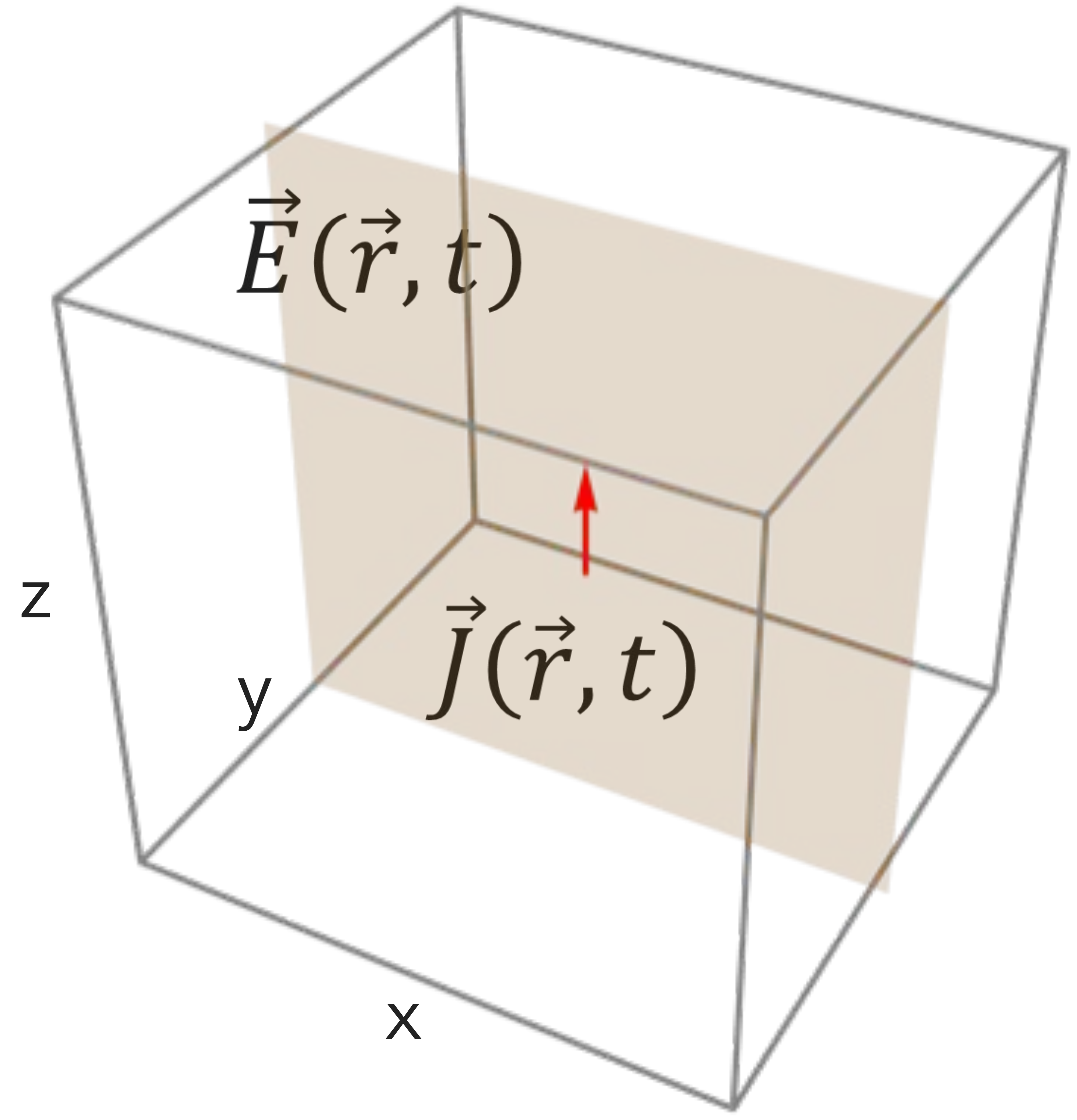
About half a billion unknowns.

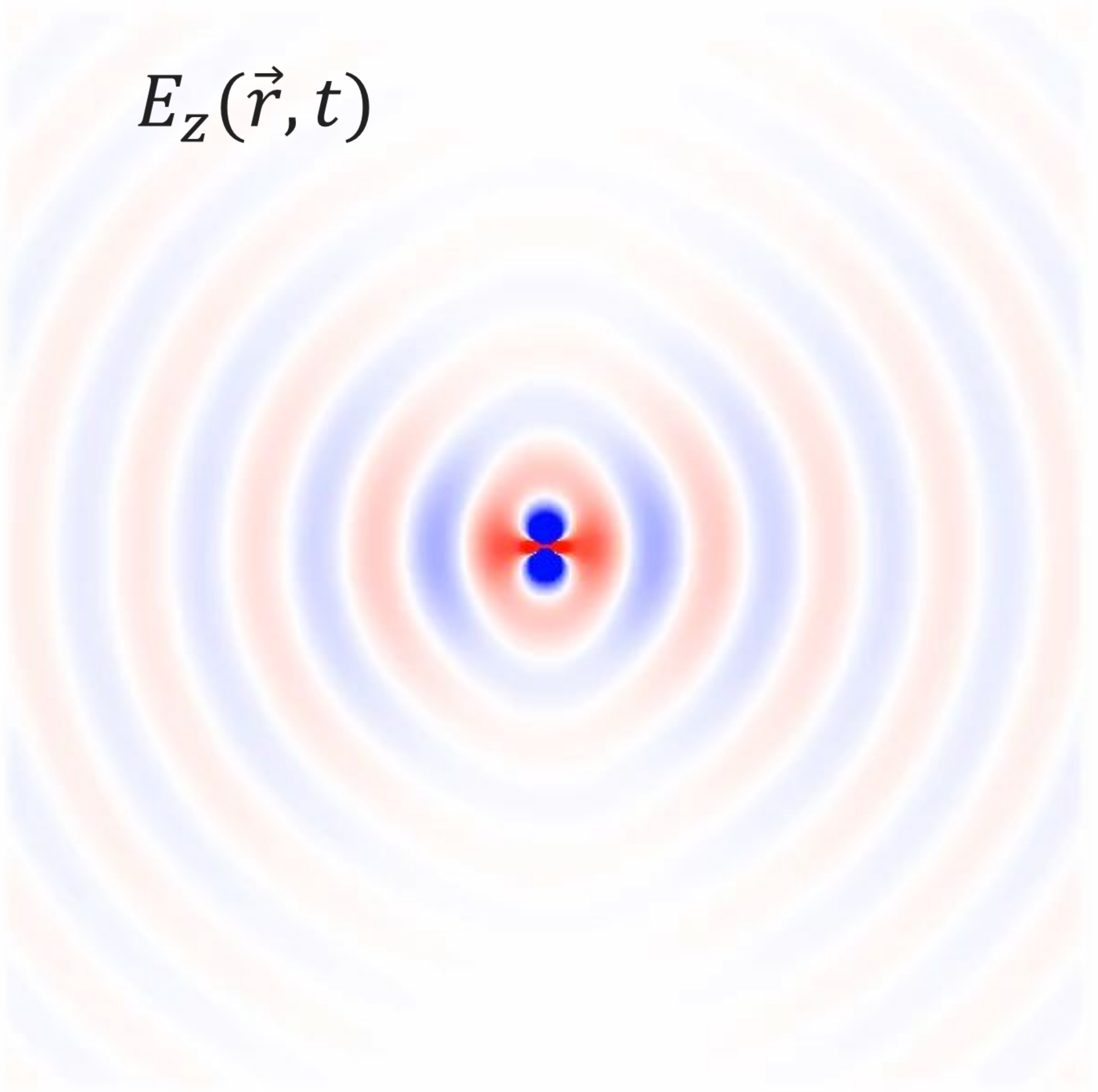
BOUNDARY CONDITIONS



Computational domain surrounded by Perfectly Matched Layers (PML), with a thickness of typically 10’s Yee cells

VACUUM





COMPLEX STRUCTURES