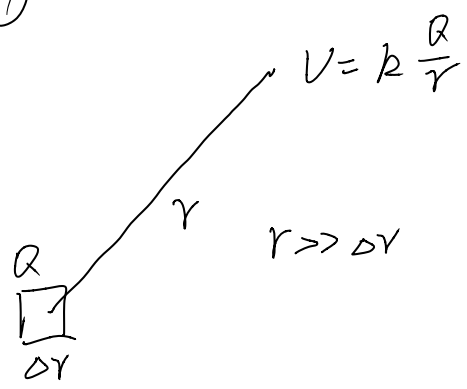
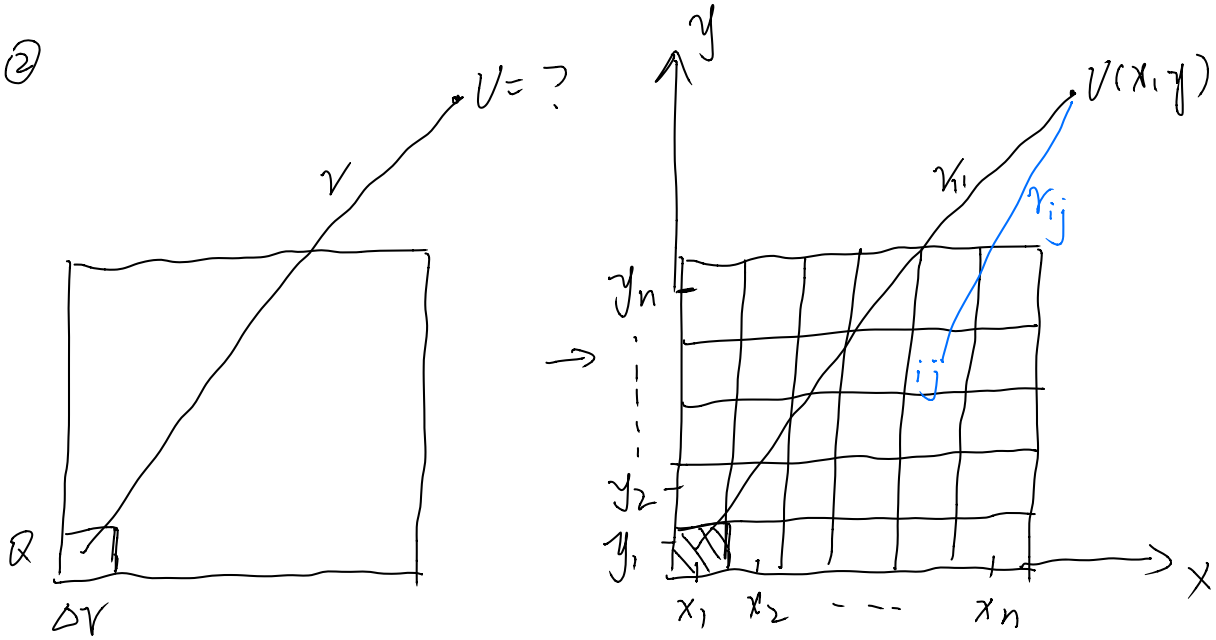
$$V = \sum_i k \frac{Q_i}{r_i} \quad , \quad \vec{E} = -\nabla V \begin{cases} E_x = -\dfrac{\partial V}{\partial x} \\ E_y = -\dfrac{\partial V}{\partial y} \end{cases}$$

①



②



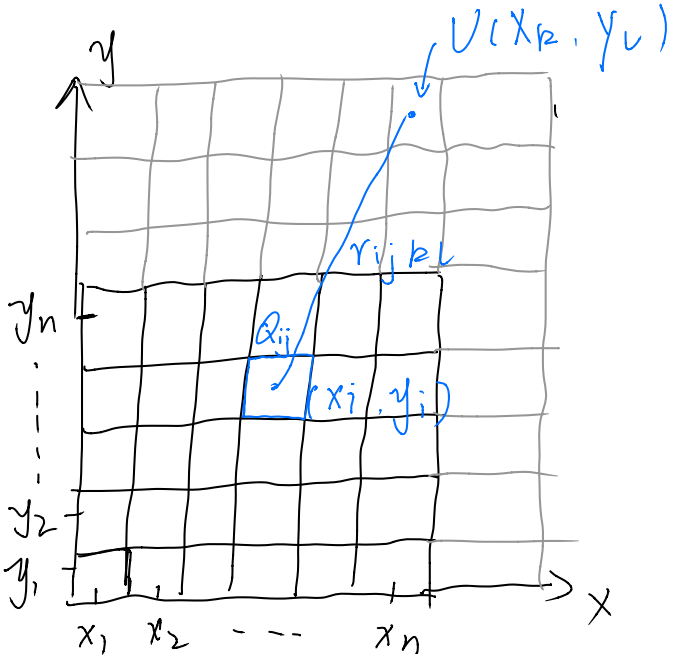
$$V(x,y) \approx k\left(\frac{Q_{11}}{r_{11}} + \frac{Q_{12}}{r_{12}} + \cdots + \frac{Q_{ij}}{r_{ij}} + \cdots\right)$$

$$r_{11} = \sqrt{(x-x_1)^2 + (y-y_1)^2}$$

$$\vdots$$

$$r_{ij} = \sqrt{(x-x_i)^2 + (y-y_j)^2}$$

数值模拟中无法描述连续的 $V(x,y)$



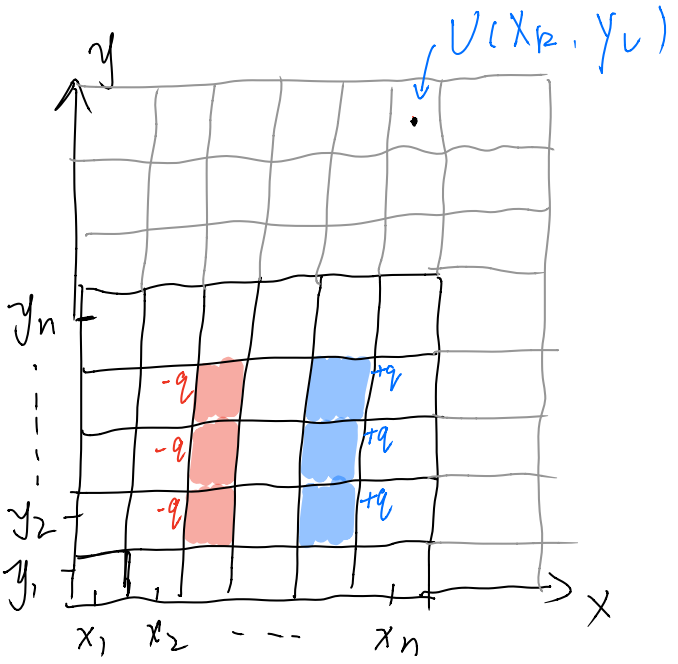
$$V(x_k, y_l) = k\left(\frac{Q_{11}}{r_{11kl}} + \cdots \frac{Q_{ij}}{r_{ijkl}} + \cdots\right)$$

$$r_{ijkl} = \sqrt{(x_k - x_i)^2 + (y_l - y_j)^2}$$

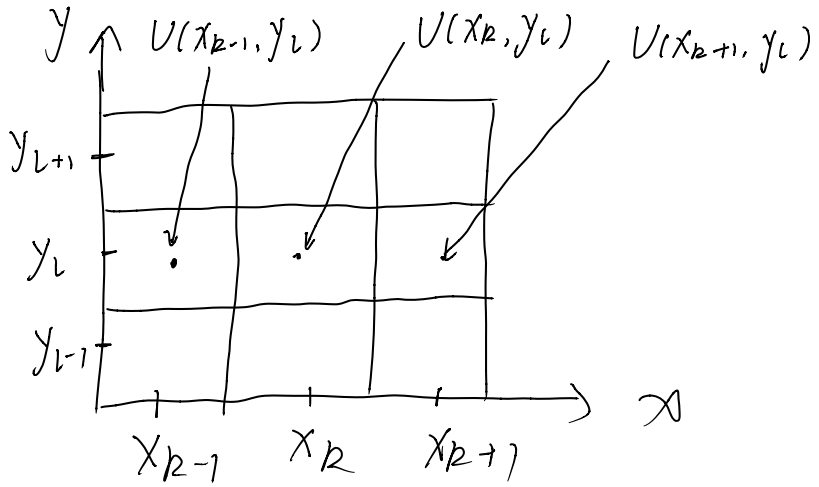
若 $Q_{11} = Q_{12} \cdots = Q_{ij} = Q$

$$U(x_k, y_l) = \sum_{ij} k \frac{Q}{r_{ijkl}}$$

③



$$U(x_k, y_l) = \sum_{ij} \begin{cases} 0 & Q_{ij} = 0 \\ kq\frac{1}{r_{ijkl}} & Q_{ij} = q \\ -kq\frac{1}{r_{ijkl}} & Q_{ij} = -q \end{cases}$$



数值求导：

$$E_x(x_k, y_l) = -\frac{dU}{dx} \approx \frac{U(x_{k+1}, y_l) - U(x_{k-1}, y_l)}{x_{k+1} - x_{k-1}}$$

$$E_y(x_k, y_l) = -\frac{dU}{dy} \approx \frac{U(x_k, y_{l+1}) - U(x_k, y_{l-1})}{y_{l+1} - y_{l-1}}$$