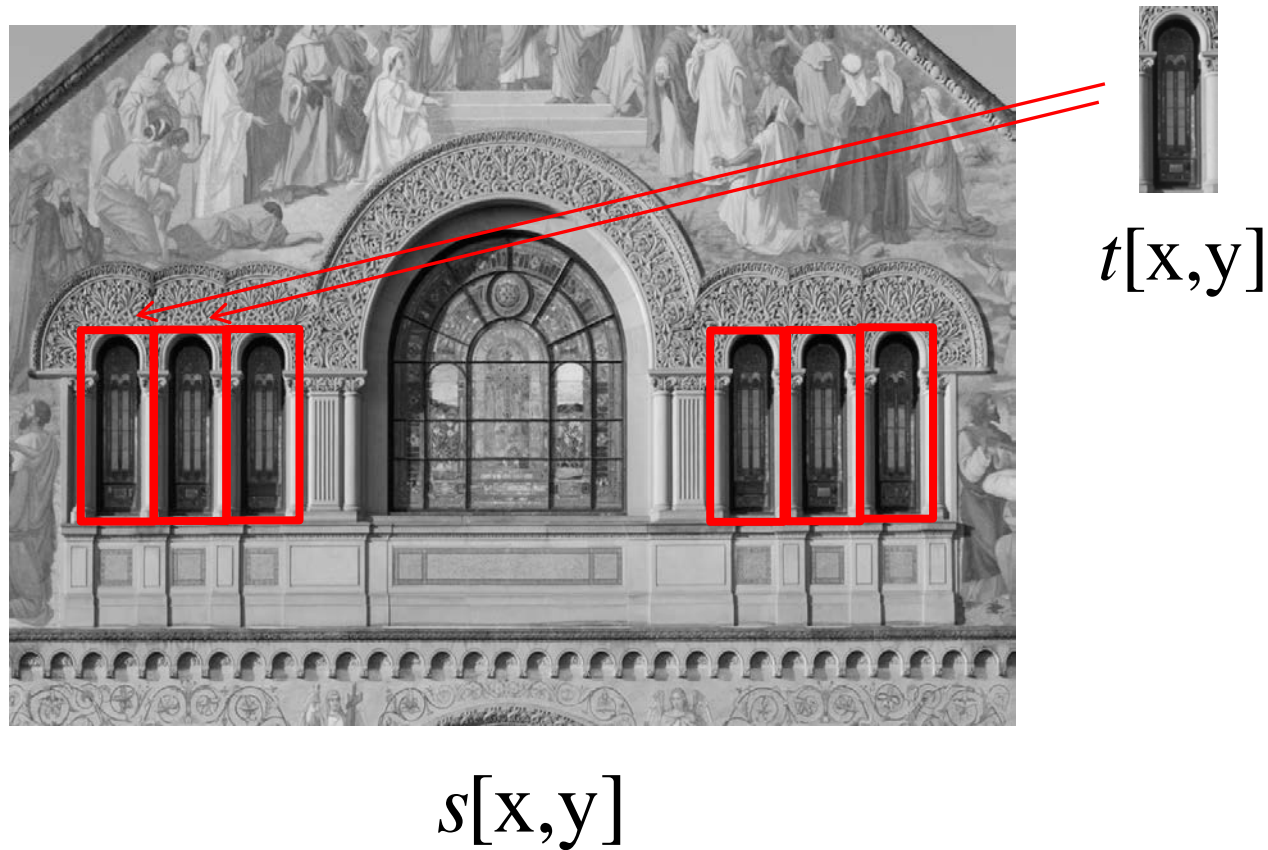


# Template matching

- Problem: locate an object, described by a template  $t[x,y]$ , in the image  $s[x,y]$
- Example



# Template matching (cont.)

- Search for the best match by minimizing mean-squared error

$$\begin{aligned} E[p, q] &= \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} \left[ s[x, y] - t[x - p, y - q] \right]^2 \\ &= \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} |s[x, y]|^2 + \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} |t[x, y]|^2 - 2 \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} s[x, y] \cdot t[x - p, y - q] \end{aligned}$$

- Equivalently, maximize *area correlation*

$$r[p, q] = \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} s[x, y] \cdot t[x - p, y - q] = s[p, q] * t[-p, -q]$$

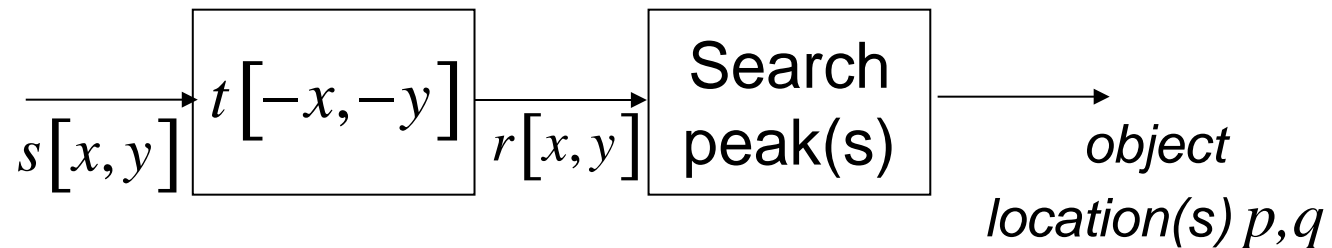
- Area correlation is equivalent to convolution of image  $s[x, y]$  with impulse response  $t[-x, -y]$

# Template matching (cont.)

- From Cauchy-Schwarz inequality

$$r[p, q] = \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} s[x, y] \cdot t[x-p, y-q] \leq \sqrt{\left( \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} |s[x, y]|^2 \right) \left( \sum_{x=-\infty}^{\infty} \sum_{y=-\infty}^{\infty} |t[x, y]|^2 \right)}$$

- Equality, iff  $s[x, y] = \alpha \cdot t[x-p, y-q]$  with  $\alpha \geq 0$
- Block diagram of template matcher



- Remove mean before template matching to avoid bias towards bright image areas

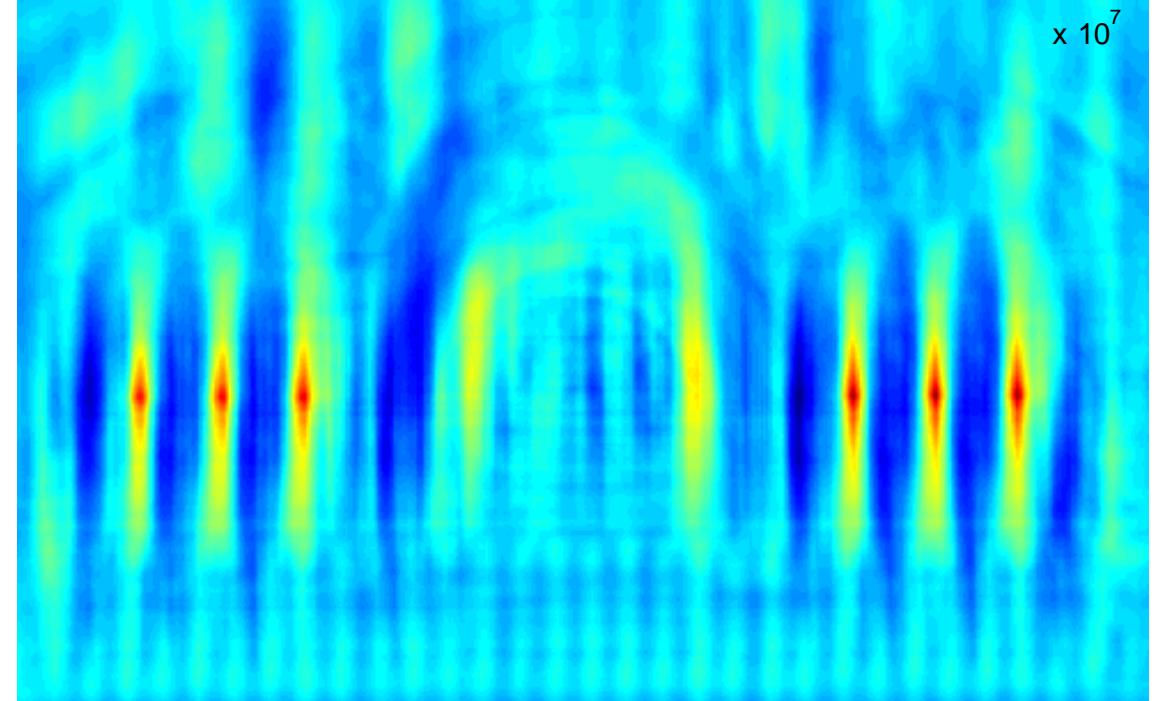
# Template matching example



$t[x,y]$



$s[x,y]$



$r[p,q]$

