Compressive Signal Processing

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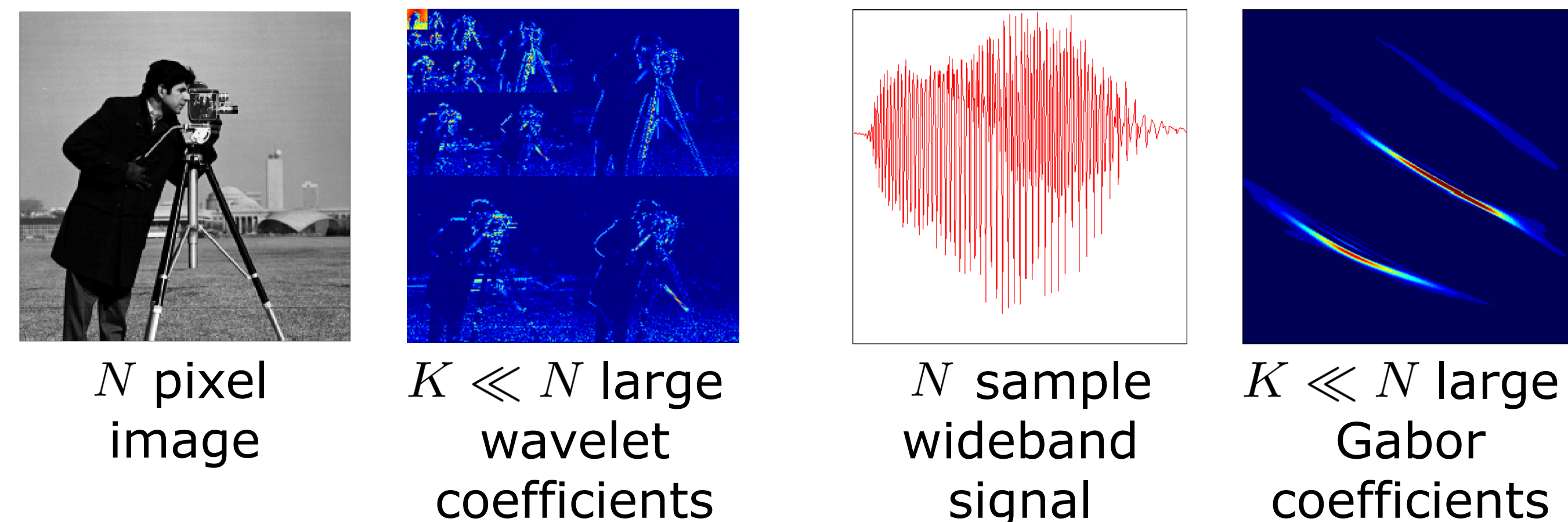
Rice University

Compressive Sensing

- Natural and man made signals often have **sparse** or **compressible** structure
- Traditional acquisition: sample then compress
- Compressive acquisition: compress and sample together

Compression and Sparsity

Traditional signal acquisition:
- *Sample* data at Nyquist rate (2x bandwidth)
- *Compress* data (signal dependent, nonlinear)

N pixel image | $K \ll N$ large wavelet coefficients | N sample wideband signal | $K \ll N$ large Gabor coefficients

Compressive Sensing (CS)

- Directly acquire *compressive measurements*
  – random projections, sketches

$M \times 1$ measurements $\quad = \quad \Phi \quad \Psi \quad \alpha$

$M \times N$ $\quad$ $N \times N$

$N \times 1$ signal

K nonzero coefficients

$$M = O(K \log(N/K)) \ll N$$

Signal Recovery

- Recovery is an ill-posed inverse problem
- Successful algorithm must *exploit sparsity*
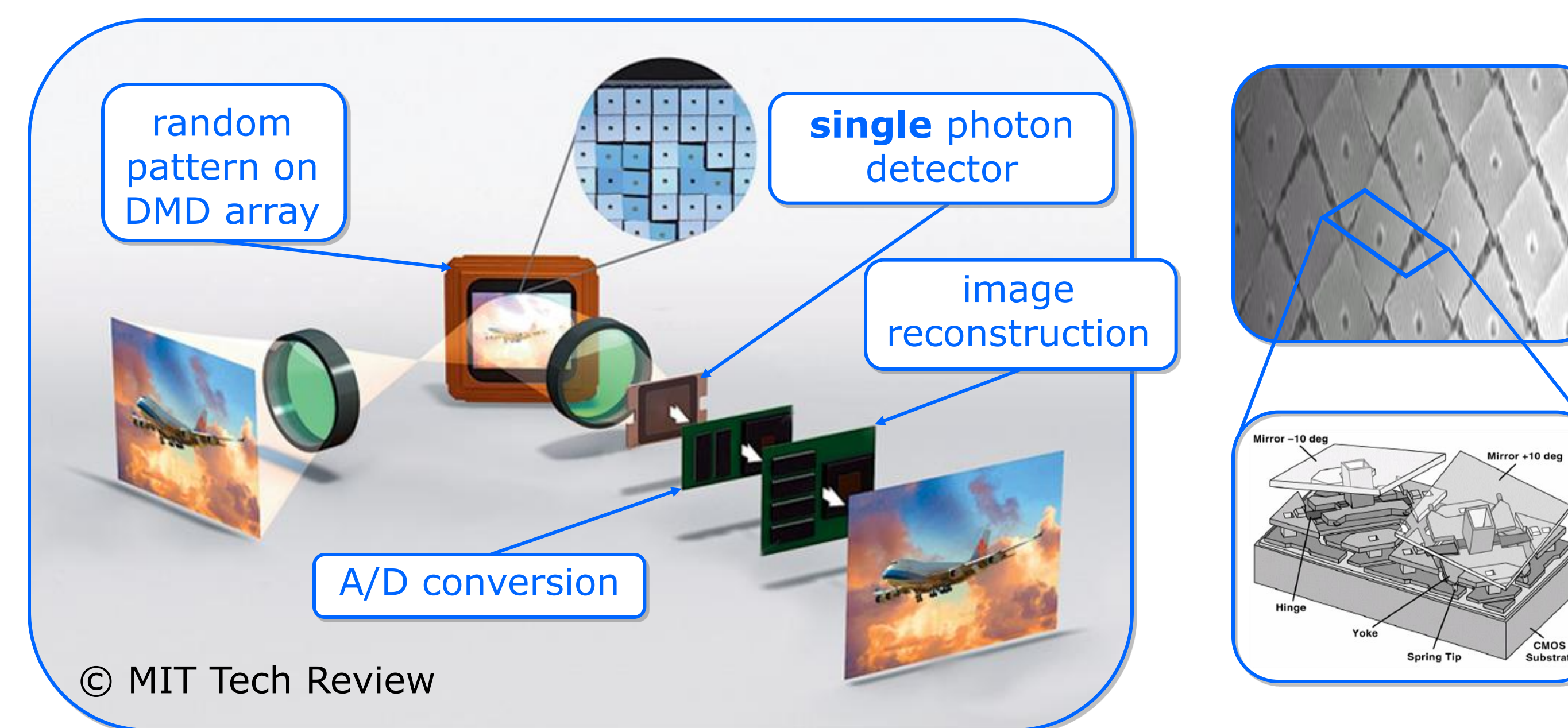 – linear programming

$$\widehat{x} = \arg\min_{\|y - \Phi x\|_2 \leq \epsilon} \|x\|_1 \qquad \|\widehat{x} - x_0\|_2 \leq C\|x^* - x_0\|_2$$

  – orthogonal matching pursuit
  – heavy-hitters algorithms
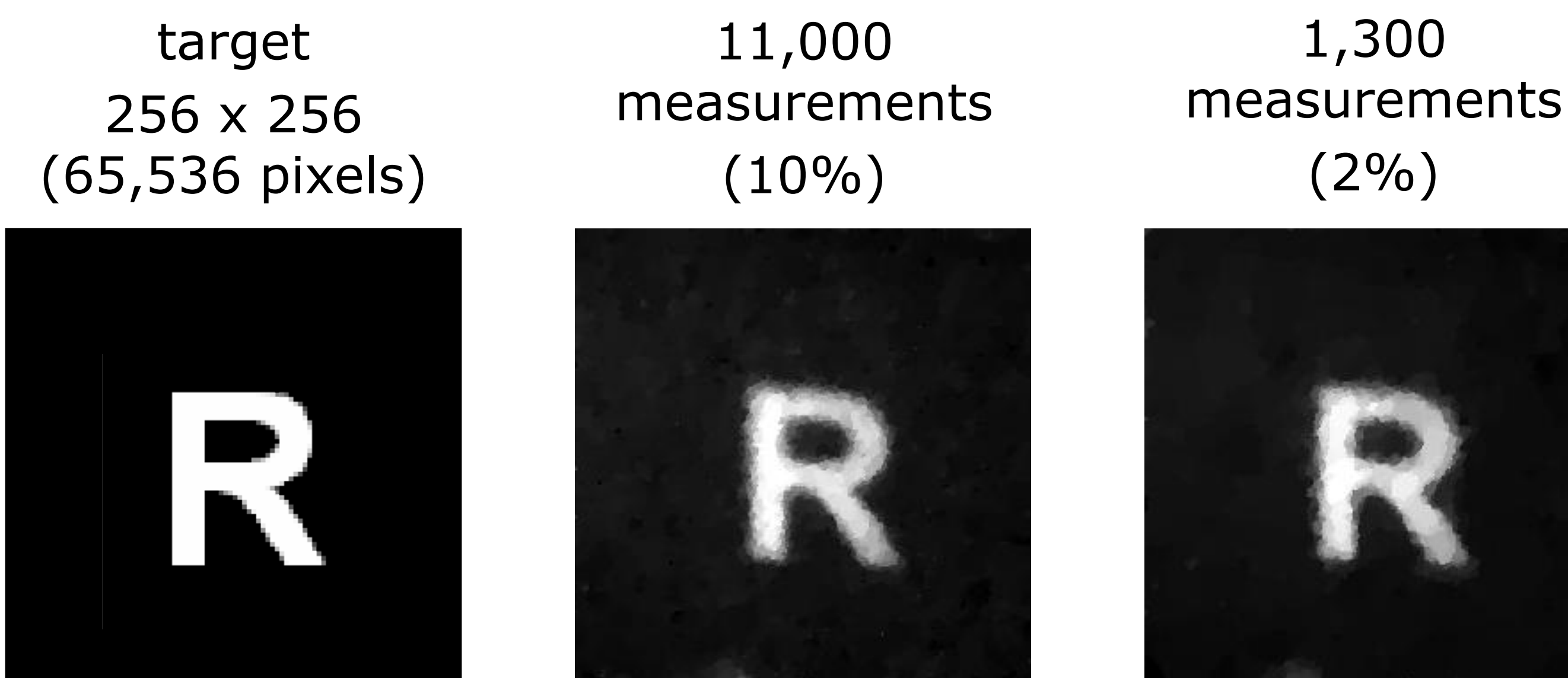 – many others

Single-pixel Camera

- Compressive imager uses **DMD** to take **projections** of the image
- Requires only **one photon sensor**
- Low cost, low power, new modalities

Camera Architecture

random pattern on DMD array | single photon detector | image reconstruction | A/D conversion

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Early Results

target 256 x 256 (65,536 pixels) | 11,000 measurements (10%) | 1,300 measurements (2%)

Color, Low-light Imaging

Photo-Multiplier Tube

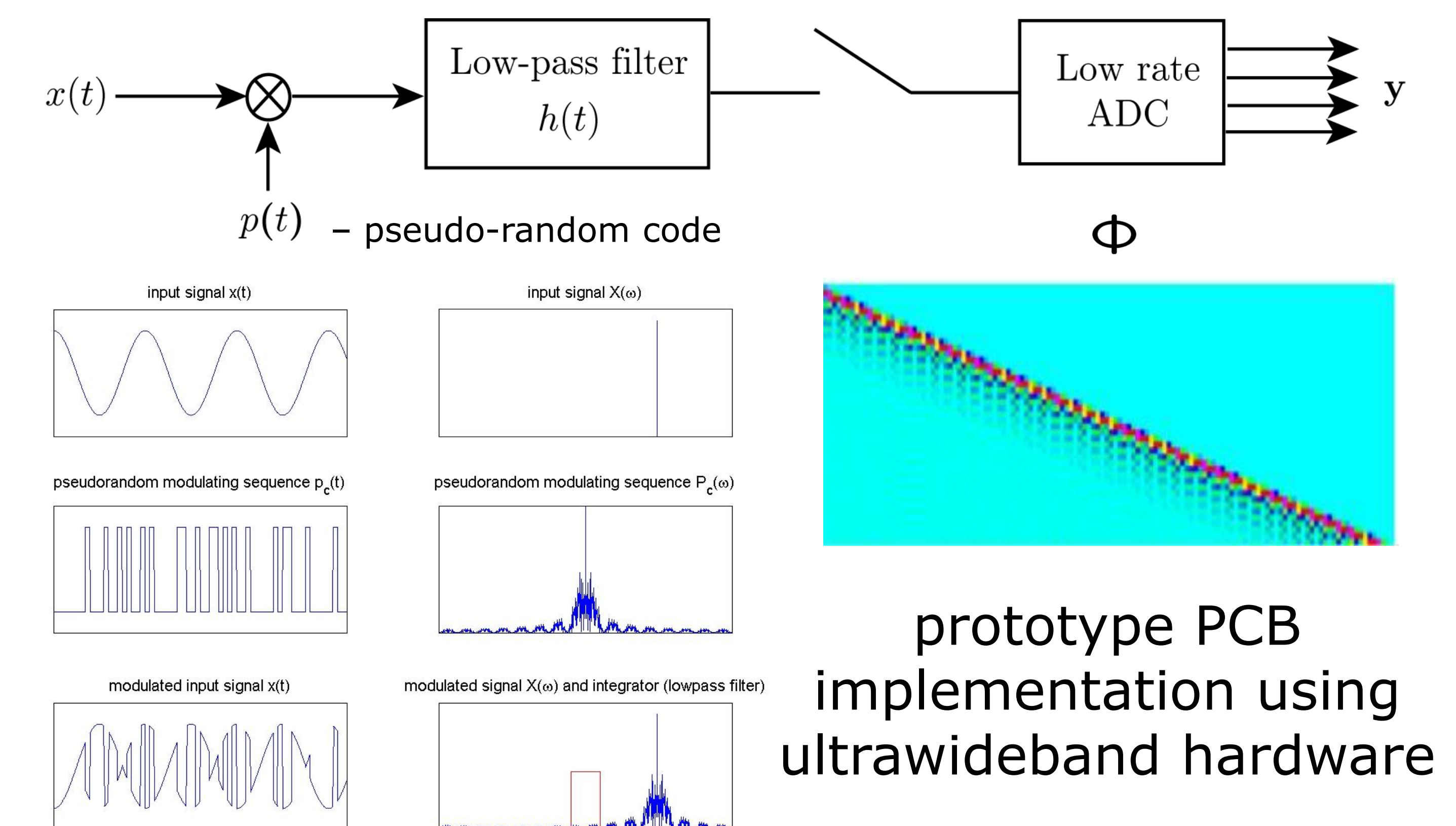- True color, low-light imaging
- 10:1 compression ratio

dsp.rice.edu/cs

Analog-to-Information Conversion

- CS enables analog-to-digital conversion at a signal's (potentially low) **information rate** rather than at the (potentially high) **Nyquist rate**
- **Smashed filter** for compressive classification

Random Demodulator AIC

$x(t)$ → Low-pass filter $h(t)$ → Low rate ADC → y

$p(t)$ – pseudo-random code

Φ

input signal x(t) | input signal X(ω)

pseudorandom modulating sequence $p_c(t)$ | pseudorandom modulating sequence $P_c(\omega)$

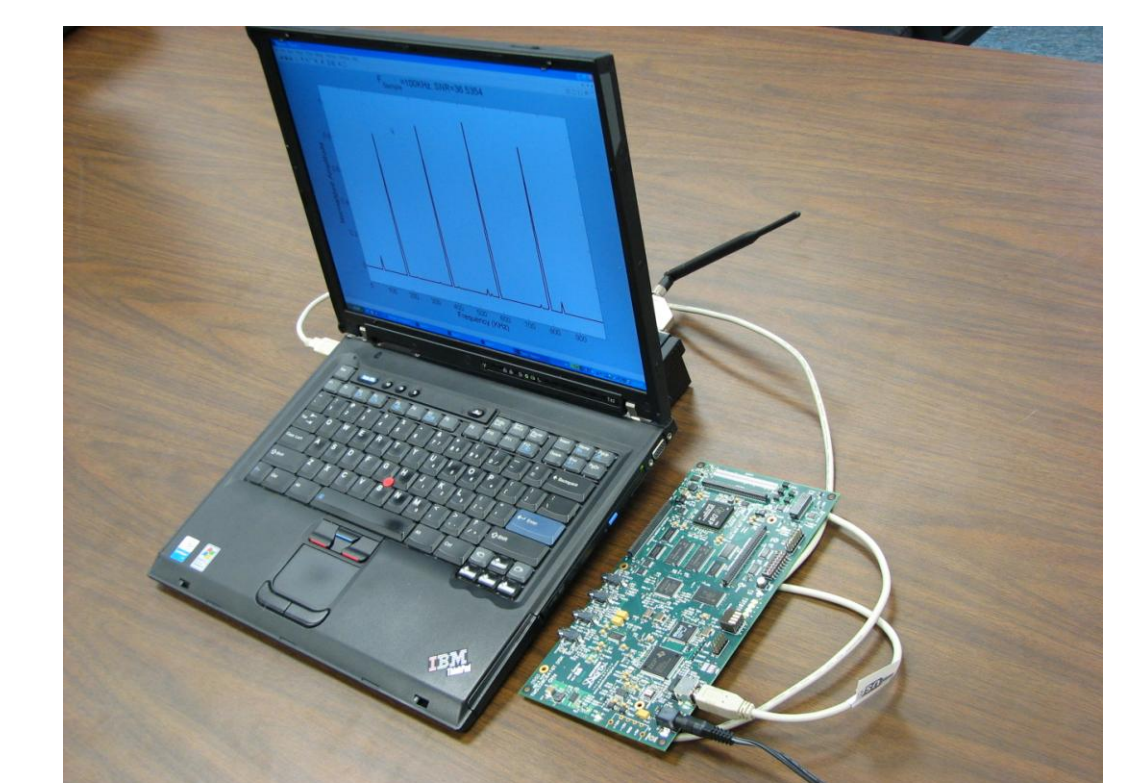modulated input signal x(t) | modulated signal X(ω) and integrator (lowpass filter)

prototype PCB implementation using ultrawideband hardware

acquisition | reconstruction

Smashed Filter

- Random measurements are *information scalable*
  – reconstruction > estimation > classification > detection
- *Smashed filter:* compressed matched filter
  – exploits random measurements/sketches and manifold structure of many classification problems

Three image classes: tank, bus, and SUV