Figure 1: Thermodynamics, a causal perspective. Extrinsic variables in green, Intrinsic ones in pink, and Legendre transforms of U in blue.

$$\Phi = U - TS - \sum_i \mu_i N_i \quad \text{(Grand Potential)} \tag{1a}$$

$$\{\mu_i\} = \frac{\partial U}{\partial \{N_i\}} \quad \text{(chemical potential for species } i) \tag{1b}$$

$$\{N_i\} = \text{prior} \quad \text{(number of particles of species } i) \tag{1c}$$

$$F = U - TS \quad \text{(Helmholtz free energy)} \tag{1d}$$

$$G = U + pV - TS \quad \text{(Gibbs free energy)} \tag{1e}$$

$$H = U + pV \quad \text{(enthalpy)} \tag{1f}$$

$$p = -\frac{\partial U}{\partial V} \quad \text{(pressure)} \tag{1g}$$

$$S = \text{prior} \quad \text{(entropy)} \tag{1h}$$

$$T = \frac{\partial U}{\partial S} \quad \text{(temperature)} \tag{1i}$$

$$U = U(S, V, \{N_i\}) \quad \text{(internal energy)} \tag{1j}$$

$$V = \text{prior} \quad \text{(volume)} \tag{1k}$$