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Constraints:

- initial state, starting conditions
- acting boundary conditions (to move within): e.g. demography, economical and political stability, labor force, education and know-how, health and technological level
- access to limited resources: e.g. chemical elements, minerals, fuels, commodities, trade and transportations, etc.
- contractual agreements and covenants, legal assurance
- juristic law framework

Modelling movement (change of state) under constraints:

1. Movement is characterized by change of energy, Lagrangian  $\mathcal{L} \neq 0$ :

$$\mathcal{L} = \mathcal{K} - \mathcal{U} \quad \frac{\partial \mathcal{L}}{\partial r} = F \quad \frac{\partial \mathcal{L}}{\partial v} = p \quad (1)$$

2. Movement happens within constraints of forces. Constraints are observable, whereas forces might be unknown. Therefore,  $r$  can be determined from  $\mathcal{L}$  (Energy and Work) of the **system at rest**  $F = 0$ , instead than from “searching” all acting forces  $F_i$ . In general, unknown forces at motion are defined by solving the Eigenvalueproblem. Solving for  $\mathcal{L}$  at equilibrium:

$$F_{total} = \hat{F}_i + \tilde{F}_i = \hat{F}_i + \sum_{k=1}^{s_d} \lambda_k a_{ki} = \frac{d}{dt} \left( \frac{\partial \mathcal{L}}{\partial v_i} \right) - \frac{\partial \mathcal{L}}{\partial r_i} = \begin{cases} = 0 : \text{Equilibrium} \\ \neq 0 : \text{Movement} \end{cases} \quad (2)$$

and at same time solving for constraining conditions that hold the system at rest (equilibrium):

$$\sum_{l=1}^f a_{kl} v_l + b_k = 0 \quad (3)$$

3. Rest is characterized by unchanged energy, Hamiltonian  $\mathcal{H} = E_{kin} + E_{pot} = const..$  There is movement from state of rest if the new  $\mathcal{H} \neq 0$  differs from the initial one. Using the found solution for the Lagrangian  $\mathcal{L}$  containing the constraints, the Hamiltonian for the energy is deduced:

$$\mathcal{H} = \sum_i p_i v_i - \mathcal{L} = pv - \mathcal{L} = Fr - \mathcal{L} = W - \mathcal{L} = (\Delta E - \Delta H) - \mathcal{L} \quad (4)$$

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4. Change of state/position is characterized by movement. Eventually, by solving the new system of differential equations, from the found solution of the energy  $\mathcal{H}$ , the set  $r, v, p$  which describe the movement (and thus the change of state), is deduced:

$$\dot{r}_i = v_i = \frac{\partial \mathcal{H}}{\partial p_i} \quad \dot{p}_i = F_i = -\frac{\partial \mathcal{H}}{\partial r_i} \quad (5)$$

see description of “work” ?@eq-workgeom

where:

$s_d = \text{constraints}$     $i = 1, \dots, f = \text{degrees of freedom}$     $k = 1, \dots, s_d = \text{constraints}$

$\hat{F}_i = \text{known constraining forces}$     $\tilde{F}_i = \sum_{k=1}^{s_d} \lambda_k a_{ki} = \text{unknown constraining forces}$

$\lambda_k(t) = \text{Eigenvalues for transformation of reference system}$

$a_{ki} = \text{Eigenvectors of transformation matrix}$

$\lambda_k \cdot \vec{r}_i = \lambda_k \cdot [a_{ki}]_{matrix}$