

Multisymplectic Geometry in Classical Field Theory

Vratko Polák

KTFDF FMFI UK BA SK

September 27, 2007

Autumn Student School on Mathematical Physics
Stará Lesná (Slovakia), 22-27th September 2007

- 1 Introduction
- 2 Formulations of mechanics
 - Lagrangian mechanics
 - Hamiltonian mechanics
- 3 Geometry of mechanics
 - Phase bundle
 - Equations of motion
 - Phase space
- 4 Classical fields
 - Lagrangian formulation
 - DeDonder-Weyl formulation
- 5 Geometry of classical fields
 - Multiphase bundle
 - Equations of motion
 - Multiphase space
- 6 Summary

Introduction

- Canonical quantization is based on Hamilton mechanics
- Classical field theory on 1D timespace is just mechanics.
- DeDonder, Weyl, Kanatchikov, ...

Introduction

- Canonical quantization is based on Hamilton mechanics
- Classical field theory on 1D timespace is just mechanics.
- DeDonder, Weyl, Kanatchikov, ...

Introduction

- Canonical quantization is based on Hamilton mechanics
- Classical field theory on 1D timespace is just mechanics.
- DeDonder, Weyl, Kanatchikov, ...



Lagrangian mechanics

- Configuration space Q
- Generalized coordinates q^a
- 1D time t
- Lagrangian $L(q, \dot{q})$
- Extended configuration space $N = Q \times \mathbb{R}$
- Extremal action principle $S[q(t)] = \int L dt$



Lagrangian mechanics

- Configuration space Q
- Generalized coordinates q^a
- 1D time t
- Lagrangian $L(q, \dot{q})$
- Extended configuration space $N = Q \times \mathbb{R}$
- Extremal action principle $S[q(t)] = \int L dt$



Lagrangian mechanics

- Configuration space Q
- Generalized coordinates q^a
- 1D time t
- Lagrangian $L(q, \dot{q})$
- Extended configuration space $N = Q \times \mathbb{R}$
- Extremal action principle $S[q(t)] = \int L dt$



Lagrangian mechanics

- Configuration space Q
- Generalized coordinates q^a
- 1D time t
- Lagrangian $L(q, \dot{q})$
- Extended configuration space $N = Q \times \mathbb{R}$
- Extremal action principle $S[q(t)] = \int L dt$



Lagrangian mechanics

- Configuration space Q
- Generalized coordinates q^a
- 1D time t
- Lagrangian $L(q, \dot{q})$
- Extended configuration space $N = Q \times \mathbb{R}$
- Extremal action principle $S[q(t)] = \int L dt$



Lagrangian mechanics

- Configuration space Q
- Generalized coordinates q^a
- 1D time t
- Lagrangian $L(q, \dot{q})$
- Extended configuration space $N = Q \times \mathbb{R}$
- Extremal action principle $S[q(t)] = \int L dt$



Hamiltonian mechanics

- Conjugated momenta $p_a = \partial L / \partial \dot{q}^a$
- Phase space P
- Hamiltonian $H(q, p) = p_a \dot{q}^a - L$
- Extended phase space $M = P \times \mathbb{R}$
- Hamiltonian action $S = \int (p_a \dot{q}^a - H) dt$



Hamiltonian mechanics

- Conjugated momenta $p_a = \partial L / \partial \dot{q}^a$
- Phase space P
- Hamiltonian $H(q, p) = p_a \dot{q}^a - L$
- Extended phase space $M = P \times \mathbb{R}$
- Hamiltonian action $S = \int (p_a \dot{q}^a - H) dt$



Hamiltonian mechanics

- Conjugated momenta $p_a = \partial L / \partial \dot{q}^a$
- Phase space P
- Hamiltonian $H(q, p) = p_a \dot{q}^a - L$
- Extended phase space $M = P \times \mathbb{R}$
- Hamiltonian action $S = \int (p_a \dot{q}^a - H) dt$



Hamiltonian mechanics

- Conjugated momenta $p_a = \partial L / \partial \dot{q}^a$
- Phase space P
- Hamiltonian $H(q, p) = p_a \dot{q}^a - L$
- Extended phase space $M = P \times \mathbb{R}$
- Hamiltonian action $S = \int (p_a \dot{q}^a - H) dt$



Hamiltonian mechanics

- Conjugated momenta $p_a = \partial L / \partial \dot{q}^a$
- Phase space P
- Hamiltonian $H(q, p) = p_a \dot{q}^a - L$
- Extended phase space $M = P \times \mathbb{R}$
- Hamiltonian action $S = \int (p_a \dot{q}^a - H) dt$

Phase bundle

- Phase bundle $\pi : M \rightarrow \mathbb{R}$
- History = section $\sigma : \mathbb{R} \rightarrow M$
- Lagrangian 1-form $L = p_a \wedge dq^a - H \wedge dt$
- Hamiltonian action $S = \int_{\sigma} L$
- $dL = dp_a \wedge dq^a - dH \wedge dt$

Phase bundle

- Phase bundle $\pi : M \rightarrow \mathbb{R}$
- History = section $\sigma : \mathbb{R} \rightarrow M$
- Lagrangian 1-form $L = p_a \wedge dq^a - H \wedge dt$
- Hamiltonian action $S = \int_{\sigma} L$
- $dL = dp_a \wedge dq^a - dH \wedge dt$

Phase bundle

- Phase bundle $\pi : M \rightarrow \mathbb{R}$
- History = section $\sigma : \mathbb{R} \rightarrow M$
- Lagrangian 1-form $L = p_a \wedge dq^a - H \wedge dt$
- Hamiltonian action $S = \int_{\sigma} L$
- $dL = dp_a \wedge dq^a - dH \wedge dt$

Phase bundle

- Phase bundle $\pi : M \rightarrow \mathbb{R}$
- History = section $\sigma : \mathbb{R} \rightarrow M$
- Lagrangian 1-form $L = p_a \wedge dq^a - H \wedge dt$
- Hamiltonian action $S = \int_{\sigma} L$
- $dL = dp_a \wedge dq^a - dH \wedge dt$

Phase bundle

- Phase bundle $\pi : M \rightarrow \mathbb{R}$
- History = section $\sigma : \mathbb{R} \rightarrow M$
- Lagrangian 1-form $L = p_a \wedge dq^a - H \wedge dt$
- Hamiltonian action $S = \int_{\sigma} L$
- $dL = dp_a \wedge dq^a - dH \wedge dt$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $\dot{q}^a = \partial H / \partial p_a$
- $\dot{p}_a = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $\dot{q}^a = \partial H / \partial p_a$
- $\dot{p}_a = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
 - Therefore $\sigma^*(i_\xi dL) = 0$
 - $\dot{q}^a = \partial H / \partial p_a$
 - $\dot{p}_a = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
 - $\dot{q}^a = \partial H / \partial p_a$
 - $\dot{p}_a = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $\dot{q}^a = \partial H / \partial p_a$
- $\dot{p}_a = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $\dot{q}^a = \partial H / \partial p_a$
- $\dot{p}_a = -\partial H / \partial q^a$

Phase space

- Phase space = fibre of phase bundle
- dL restricts to $\omega = dp_a \wedge dq^a$
- Observables generate symplectomorphisms $i_{\xi_f} \omega = -df$
- Poisson algebra $\{f, g\} = i_{\xi_g} i_{\xi_f} \omega$
- Phase space = space of solutions of equations of motion

Phase space

- Phase space = fibre of phase bundle
- dL restricts to $\omega = dp_a \wedge dq^a$
- Observables generate symplectomorphisms $i_{\xi_f} \omega = -df$
- Poisson algebra $\{f, g\} = i_{\xi_g} i_{\xi_f} \omega$
- Phase space = space of solutions of equations of motion

Phase space

- Phase space = fibre of phase bundle
- dL restricts to $\omega = dp_a \wedge dq^a$
- Observables generate symplectomorphisms $i_{\xi_f} \omega = -df$
- Poisson algebra $\{f, g\} = i_{\xi_g} i_{\xi_f} \omega$
- Phase space = space of solutions of equations of motion

Phase space

- Phase space = fibre of phase bundle
- dL restricts to $\omega = dp_a \wedge dq^a$
- Observables generate symplectomorphisms $i_{\xi_f} \omega = -df$
- Poisson algebra $\{f, g\} = i_{\xi_g} i_{\xi_f} \omega$
- Phase space = space of solutions of equations of motion

Phase space

- Phase space = fibre of phase bundle
- dL restricts to $\omega = dp_a \wedge dq^a$
- Observables generate symplectomorphisms $i_{\xi_f} \omega = -df$
- Poisson algebra $\{f, g\} = i_{\xi_g} i_{\xi_f} \omega$
- Phase space = space of solutions of equations of motion



Lagrangian formulation

- Configuration space Q
- Generalized coordinates q^a
- nD spacetime x^μ
- Lagrangian $L(q, q_{,\mu})$
- Extended configuration space $N = Q \times \mathbb{R}^k$
- Extremal action principle $S[q(t)] = \int L \Omega_g$

Lagrangian formulation

- Configuration space Q
- Generalized coordinates q^a
- nD spacetime x^μ
- Lagrangian $L(q, q_{,\mu})$
- Extended configuration space $N = Q \times \mathbb{R}^k$
- Extremal action principle $S[q(t)] = \int L \Omega_g$

Lagrangian formulation

- Configuration space Q
- Generalized coordinates q^a
- **nD spacetime x^μ**
- Lagrangian $L(q, q_{,\mu})$
- Extended configuration space $N = Q \times \mathbb{R}^k$
- Extremal action principle $S[q(t)] = \int L \Omega_g$



Lagrangian formulation

- Configuration space Q
- Generalized coordinates q^a
- **nD spacetime x^μ**
- Lagrangian $L(q, q, \mu)$
 - Extended configuration space $N = Q \times \mathbb{R}^k$
 - Extremal action principle $S[q(t)] = \int L \Omega_g$



Lagrangian formulation

- Configuration space Q
- Generalized coordinates q^a
- **nD spacetime** x^μ
- Lagrangian $L(q, q, \mu)$
- Extended configuration space $N = Q \times \mathbb{R}^k$
- Extremal action principle $S[q(t)] = \int L \Omega_g$



Lagrangian formulation

- Configuration space Q
- Generalized coordinates q^a
- **nD spacetime** x^μ
- Lagrangian $L(q, q_{,\mu})$
- Extended configuration space $N = Q \times \mathbb{R}^k$
- Extremal action principle $S[q(t)] = \int L \Omega_g$



DeDonder-Weyl formulation

- Conjugated multimomenta $p_a^\mu = \partial L / \partial q_{, \mu}^a$
- Multiphase space P
- DeDonder Hamiltonian $H(q, p) = p_a^\mu q_{, \mu}^a - L$
- Extended multiphase space $M = P \times \mathbb{R}^k$
- DeDonder Hamiltonian action $S = \int (p_a^\mu q_{, \mu}^a - H) \Omega_g$



DeDonder-Weyl formulation

- Conjugated multimomenta $p_a^\mu = \partial L / \partial q_{,\mu}^a$
- Multiphase space P
- DeDonder Hamiltonian $H(q, p) = p_a^\mu q_{,\mu}^a - L$
- Extended multiphase space $M = P \times \mathbb{R}^\kappa$
- DeDonder Hamiltonian action $S = \int (p_a^\mu q_{,\mu}^a - H) \Omega_g$

DeDonder-Weyl formulation

- Conjugated multimomenta $p_a^\mu = \partial L / \partial q_{,\mu}^a$
- Multiphase space P
- DeDonder Hamiltonian $H(q, p) = p_a^\mu q_{,\mu}^a - L$
- Extended multiphase space $M = P \times \mathbb{R}^\kappa$
- DeDonder Hamiltonian action $S = \int (p_a^\mu q_{,\mu}^a - H) \Omega_g$

DeDonder-Weyl formulation

- Conjugated multimomenta $p_a^\mu = \partial L / \partial q_{,\mu}^a$
- Multiphase space P
- DeDonder Hamiltonian $H(q, p) = p_a^\mu q_{,\mu}^a - L$
- Extended multiphase space $M = P \times \mathbb{R}^\kappa$
- DeDonder Hamiltonian action $S = \int (p_a^\mu q_{,\mu}^a - H) \Omega_g$

DeDonder-Weyl formulation

- Conjugated multimomenta $p_a^\mu = \partial L / \partial q_{,\mu}^a$
- Multiphase space P
- DeDonder Hamiltonian $H(q, p) = p_a^\mu q_{,\mu}^a - L$
- Extended multiphase space $M = P \times \mathbb{R}^\kappa$
- DeDonder Hamiltonian action $S = \int (p_a^\mu q_{,\mu}^a - H) \Omega_g$

Multiphase bundle

- Multiphase bundle $\pi : M \rightarrow \mathbb{R}^k$
- History = section $\sigma : \mathbb{R}^k \rightarrow M$
- Lagrangian n-form $L = p_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - H \wedge \Omega_g$
- DeDonder Hamiltonian action $S = \int_\sigma L$
- $dL = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - dH \wedge \Omega_g$



Multiphase bundle

- Multiphase bundle $\pi : M \rightarrow \mathbb{R}^k$
- History = section $\sigma : \mathbb{R}^k \rightarrow M$
- Lagrangian n-form $L = p_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - H \wedge \Omega_g$
- DeDonder Hamiltonian action $S = \int_\sigma L$
- $dL = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - dH \wedge \Omega_g$

Multiphase bundle

- Multiphase bundle $\pi : M \rightarrow \mathbb{R}^k$
- History = section $\sigma : \mathbb{R}^k \rightarrow M$
- Lagrangian n-form $L = p_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - H \wedge \Omega_g$
- DeDonder Hamiltonian action $S = \int_\sigma L$
- $dL = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - dH \wedge \Omega_g$

Multiphase bundle

- Multiphase bundle $\pi : M \rightarrow \mathbb{R}^k$
- History = section $\sigma : \mathbb{R}^k \rightarrow M$
- Lagrangian n-form $L = p_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - H \wedge \Omega_g$
- DeDonder Hamiltonian action $S = \int_\sigma L$
- $dL = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - dH \wedge \Omega_g$

Multiphase bundle

- Multiphase bundle $\pi : M \rightarrow \mathbb{R}^k$
- History = section $\sigma : \mathbb{R}^k \rightarrow M$
- Lagrangian n-form $L = p_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - H \wedge \Omega_g$
- DeDonder Hamiltonian action $S = \int_\sigma L$
- $dL = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g) - dH \wedge \Omega_g$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
 - Movement is relative: σ stays, L moves.
 - $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
 - Therefore $\sigma^*(i_\xi dL) = 0$
 - $q^a{}_{,\mu} = \partial H / \partial p_a^\mu$
 - $p_a^\mu{}_{,\mu} = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
 - $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
 - Therefore $\sigma^*(i_\xi dL) = 0$
 - $q^a{}_{,\mu} = \partial H / \partial p_a^\mu$
 - $p_a^\mu{}_{,\mu} = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $q^a{}_{,\mu} = \partial H / \partial p_a^\mu$
- $p_a^\mu{}_{,\mu} = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
 - $q^a{}_{,\mu} = \partial H / \partial p_a^\mu$
 - $p_a^\mu{}_{,\mu} = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $q^a{}_{,\mu} = \partial H / \partial p_a^\mu$
- $p_a^\mu{}_{,\mu} = -\partial H / \partial q^a$



Equations of motion

- Variation of $\sigma =$ vertical vector field ξ defined at least on σ
- Movement is relative: σ stays, L moves.
- $\mathcal{L}_\xi L = di_\xi L + i_\xi dL$
- Therefore $\sigma^*(i_\xi dL) = 0$
- $q^a{}_{,\mu} = \partial H / \partial p_a^\mu$
- $p_a^\mu{}_{,\mu} = -\partial H / \partial q^a$

Multiphase space

- Multiphase space = fibre of multiphase bundle
- dL restricts to $\omega = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g)$
- Phase space \neq space of solutions of equations of motion
- **Observables do not generate multisymplectomorphisms**

Multiphase space

- Multiphase space = fibre of multiphase bundle
- dL restricts to $\omega = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g)$
- Phase space \neq space of solutions of equations of motion
- Observables do not generate multisymplectomorphisms

Multiphase space

- Multiphase space = fibre of multiphase bundle
- dL restricts to $\omega = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g)$
- Phase space \neq space of solutions of equations of motion
- Observables do not generate multisymplectomorphisms

Multiphase space

- Multiphase space = fibre of multiphase bundle
- dL restricts to $\omega = dp_a^\mu \wedge dq^a \wedge (i_\mu \Omega_g)$
- Phase space \neq space of solutions of equations of motion
- **Observables do not generate multisymplectomorphisms**

Multisymplectic Geometry

- Classical fields as multidimensional mechanics
- Very similar but not for quantization.
- Thank you.

Multisymplectic Geometry

- Classical fields as multidimensional mechanics
- Very similar but not for quantization.
- Thank you.

Multisymplectic Geometry

- Classical fields as multidimensional mechanics
- Very similar but not for quantization.
- Thank you.