Perspectives on Higher and Lower Form Symmetries

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Outline

- Introduction to Generalized Global Symmetries
- Higher Form Symmetries
- Gauging Higher Form Symmetries
- Lower Form Symmetries
- Generalized Abelian Gauge Theories
- Anomaly Field Theories for Dual Gauge Fields

Standard Symmetries in QFT

- Textbook symmetries: a global continuous symmetry on M corresponds to a conserved Noether current $J \in \Omega^1(M)$: $\mathrm{d} * J = 0$

- Integrating J^0 over a spatial hypersurface $\Sigma \subset M$ at fixed time gives a conserved Noether charge $Q_\Sigma = \int_\Sigma \mathrm{d}\Sigma \, J^0$

  In quantum theory it generates the symmetry on the Hilbert space

- By relativistic invariance, it is more natural to integrate over any codimension 1 submanifold $\Sigma \subset M$: $Q_\Sigma = \int_\Sigma *J$, which is conserved in normal direction to Σ

- $\exp(\mathrm{i}\,\alpha\, Q_\Sigma) =$ topological operator of codimension 1: depends only on homology class of Σ by Stokes' Theorem and $\mathrm{d} * J = 0$

- Generalization: Submanifolds Σ of higher codimension, or forms J of higher degree

Generalized Symmetries

- Textbook symmetries in QFT are *group* actions on *local* operators

- Relax 'local' $\Longleftrightarrow$ higher form symmetries are *group* actions on all operators

- Relax 'group' $\Longleftrightarrow$ non-invertible symmetries are categorical actions on *local* operators

- Combinations of the two are categorical actions on all operators

- Modern paradigm: (Gaiotto, Kapustin, Seiberg & Willet '14; ...)

  Symmetries of QFT are topological operators

- "Generalized symmetries" of QFT are described by **higher algebra**, whose action should be defined on objects with higher linear structures (e.g. higher vector bundles)

Higher Form Symmetries

- Classical symmetries that survive quantization
- p-form symmetries correspond to topological operators of codim $(p+1)$, act on p-dimensional charged operators by linking, multiply by fusion; for $p > 0$ described by *abelian* groups (local = '0-form symmetries')
- **Example:** Pure d-dimensional Yang-Mills theory with simply-connected gauge group G: Centre $Z \subset G$ acts trivially on local gauge-invariant operators, but non-trivally on Wilson lines; finite electric 1-form symmetry
- Combinations of higher form symmetries can merge into higher groups; e.g. 1-form symmetry H combines with 0-form symmetry G to form a 2-group extension $1 \longrightarrow BH \longrightarrow \underline{\Gamma} \longrightarrow G \longrightarrow 1$
- Expectation: Topological operators of a d-dimensional QFT form a $(d-1)$-category (Johnson-Freyd '20; Bhardwaj, Schäfer-Nameki & Wu '22)
- p-form symmetries are p-morphisms in this higher category
- Accounts for topological operators of codimensions $1, \ldots, d$, that is, p-form symmetries with $0 \leqslant p \leqslant (d-1)$

Non-Invertible Symmetries

- Quantum symmetries described by (higher) rings or algebras
- Topological operators closely related to 'symmetry defects' in QFT, described using (higher) categorical algebra
  (Fuchs, Runkel & Schweigert '02; ...)
- **Example:** Pure $SU(N)$ Yang-Mills theory on a surface Σ ($d = 2$):
  - For $x \in \Sigma$ and $U_0 \in SU(N)$, take path integral over gauge connections A with holonomy in conjugacy class $[U_0]$ on $\Sigma \setminus x$
  - Defines local topological symmetry operator $V[U_0]$ (analogue of Gukov-Witten operator in $d = 4$) (Nguyen, Tanizaki & Ünsal '21)
  - When Σ = disk , W_R = Wilson line along $\partial\Sigma$ in irrep R:

    $$\langle V[U_0]\, W_R \rangle = \chi_R(U_0)\ \mathrm{e}^{-\frac{g^2}{4}\, C_2(R)}$$

    Vanishes for a large set of U_0 and R $\Longrightarrow$ non-invertible 1-form symmetry
  - Imposing invertibility fixes $U_0 \in Z = \mathbb{Z}_N$ and recovers usual 1-form centre symmetry

SymTFT Picture

- Generalized symmetries of any d-dimensional QFT $\mathcal{Q}$ on M define a $(d+1)$-dimensional TQFT $\mathrm{Sym}(\mathcal{Q})$ on X – the Symmetry Topological Field Theory (SymTFT) – such that $\mathcal{Q}$ and its p-form group symmetries can be recovered from $\mathrm{Sym}(\mathcal{Q})$ by manipulations on ∂X

  (Freed & Teleman '12; Pulman, Ševera & Valach '19; Gaiotto & Kulp '20; Freed, Moore & Teleman '22; Borsten, Kanakaris & Kim '25; ...)

- 'Sandwich Construction' on $X = M \times [0,1]$:
  - $M \times 0$: Dynamical boundary where non-topological theory $\mathcal{Q}$ lives
  - $M \times 1$: Topological boundary conditions (domain wall) on SymTFT fields depending solely on symmetries of $\mathcal{Q}$

- Insertion of topological defects in X: Since $[0,1]$ is contractible, collapsing slab gives theory $\mathcal{Q}$ on M

- Isolate geometric aspects by taking $X = M \times [0,\infty)$ (no effect on topological data)

- Formally, $\mathrm{Sym}(\mathcal{Q})$ is a fully extended $(d+1)$-dimensional TQFT, boundary conditions are modules

Gauging Symmetries

Symmetries can be gauged, giving orbifold QFT with dual symmetry (not necessarily invertible) which is undone by reverse orbifold

- 0-form symmetry in $d = 2$ dimensions $\xrightarrow{\text{gauge}}$ dual (or 'quantum') 0-form symmetry (Vafa '89)
- p-form symmetry in d dimensions $\xrightarrow{\text{gauge}}$ dual $(d - p - 2)$-form symmetry (Gaiotto, Kapustin, Seiberg & Willet '14; Tachikawa '17)
- p-form symmetry in d dimensions $\xrightarrow{\text{gauge}}$ dual category (Bhardwaj & Tachikawa '17; Chang, Lin, Shao, Wang & Yin '18)
- **Example:** Pure d-dimensional Yang-Mills theory with simply-connected gauge group G, centre $Z \subset G$

  Electric 1-form symmetry $Z \xrightarrow{\text{gauge}}$ d-dimensional Yang-Mills theory with gauge group $PG = G/Z$ and magnetic $(d-3)$-form symmetry $\widehat{Z} = \mathrm{Hom}\big(Z, U(1)\big)$ acting on 't Hooft operators

Gauge Fields for Finite Symmetries

- Gauge field for a p-form symmetry $\mathbb{Z}_n \subset U(1)$ on M has periods in $\mathbb{Z}_n$
- Alternatively, a pair of $U(1)$ gauge fields $(A, B) \in \Omega^p(M) \times \Omega^{p+1}(M)$ with $n\,B \;=\;$ curvature of A: Replace $\mathbb{Z}_n$ gauge field by its $U(1)$ avatar $\frac{n}{2\pi}\,B$
- Pair (B, A) defines a **$(p+1)$-connection on a p-gerbe** on M:

$$
\begin{array}{ccccccccc}
0 & \longrightarrow & \mathbb{Z} & \longrightarrow & \underline{\mathbb{R}} & \longrightarrow & \underline{U(1)} & \longrightarrow & 0 \\
 & & \Big\uparrow{\scriptstyle \mathbb{1}} & & \Big\uparrow{\scriptstyle \iota} & & \Big\uparrow & & \\
0 & \longrightarrow & \mathbb{Z} & \longrightarrow & \frac{1}{n}\,\mathbb{Z} & \longrightarrow & \mathbb{Z}_n & \longrightarrow & 0
\end{array}
$$

- Regard $\mathbb{Z}_n$-gerbes as $U(1)$-gerbes restricted to image of Bockstein homomorphism $H^{p+1}(M, \mathbb{Z}_n) \longrightarrow H^{p+2}(M, \mathbb{Z})$
- $\mathbb{Z}_n$ gauge field is $\iota^* B$ for $(p+1)$-form $U(1)$ gauge field B
- Implement constraint by Lagrange multiplier in path integral

Lower Form Symmetries

What is the meaning of (invertible) **lower form** symmetries?

- There are **no** operators of dimension $p \leqslant -1$ to act on

- A (-1)-form symmetry **is** generated by topological operators filling the connected components of spacetime, modify defining parameters of theory
(Córdova, Freed, Lam & Seiberg '19)

- Gauging **is** 'reversible': gauging a $(d-1)$-form symmetry (generated by local topological operators) must produce a dual (-1)-form symmetry
(Sharpe '19; Wu '20)

- Consider full family of QFTs fibred over parameter space X of the theory:
Symmetries are automorphisms of the fibration QFT $\longrightarrow X$
(Gaiotto & Kulp '20; Vandermeulen '22; Heckman, Hübner & Murdia '24; Santilli & Sz '24)

- p-form symmetries act fibrewise on QFT_x for each $x \in X$ if $p \geqslant 0$, on base X if $p \leqslant -1$

- Including physical theory in larger descent structure allows for $p \leqslant -1$
(Antinucci & Benini '24; Borsten, Kanakaris & Kim '25)

Lower Form Symmetries

Problem: What is a gauge field for a (-1)-form symmetry?

- Useful perspective: An invertible p-form symmetry on M is a ***p*-gerbe**, gauge field is a $(p+1)$-connection (Santilli & Sz '24)
- Modelled by differential $(p+2)$-cocycle with curvature $F \in \Omega^{p+2}_{\mathbb{Z}}(M)$ and characteristic class in $H^{p+2}(M, \mathbb{Z})$
- Assemble into the structure of a $(p+1)$-groupoid, classes for differential cohomology $\hat{H}^{p+2}(M)$; e.g. in Deligne cohomology:
  - $p = -2$: Differential 0-cocycle is a class in group of connected components $H^0(M, \mathbb{Z})$
  - $p = -1$: Differential 1-cocycle is a function $f : M \longrightarrow U(1)$, curvature $F = \mathrm{d} \log f$ represents winding number in $H^1(M, \mathbb{Z})$
  - $p = 0$: Differential 2-cocycle is a $U(1)$-bundle with connection A, curvature $F = \mathrm{d}A$ represents Chern class in $H^2(M, \mathbb{Z})$
  - $p = 1$: Differential 3-cocycle is a $U(1)$-gerbe with 2-connection (A, B), $F = \mathrm{d}B$ represents Dixmier-Douady class in $H^3(M, \mathbb{Z})$

Lower Form Symmetries

- **Chern-Weil symmetries:** Continuous abelian (-1)-form symmetries, background fields are couplings for characteristic classes in the theory

- **Example:** $SU(N)$ Yang-Mills theory in $d=4$ with θ-angle

$$\frac{\theta}{8\pi^2}\,\mathrm{Tr}\,(F\wedge F)$$

  Invariance under $\theta\longmapsto\theta+2\pi$ is invariance under large background gauge transformations

- Gauging means promoting θ to spacetime dependent field $\theta(x)$ and treating it as background gauge field

- Dual theory with 3-form symmetry is formally an infinite 'sum' over all θ

- Decomposition conjecture: QFT in d dimensions with $(d-1)$-form symmetry is equivalent to disjoint union of theories ('universes') in which symmetry is gauged using local topological operators

  (Hellerman, Henriques, Pantev, Sharpe & Ando '06; Sharpe '14; ...)

Lower Form Symmetries

Open problem: Cast (-1)-form symmetries in categorical setting, to get intrinsic explanation of gauging a $(d-1)$-form symmetry

- Category of topological operators in SymTFT (in $(d+1)$ dimensions) will include (-1)-form symmetry generators; iterations $\mathrm{SymTFT} \circ \mathrm{SymTFT} \circ \cdots$ allow for more general $p \leqslant -1$

- Non-invertible (-1)-form symmetry; e.g. gauging non-invertible 1-form symmetry of pure Yang-Mills theory in $d=2$ (Santilli & Sz '24)

- Modify notion of symmetry category: View as d-category whose objects are d-dimensional QFTs, morphisms are topological interfaces between QFTs (Wu '20; Perez-Lona '25)

  Symmetry category of an object $\mathcal{Q}$ is the $(d-1)$-category $\mathrm{End}(\mathbb{1}_{\mathcal{Q}})$, but does not capture (-1)-form symmetries which are more naturally embedded in the whole d-category

Generalized Abelian Gauge Theories

$$S = \frac{1}{2}\int_M F\wedge *F$$

M = closed d-dimensional manifold with metric

$F\in\Omega^{p+1}_{\mathbb{Z}}(M)$; locally $F = \mathrm{d}A$ for $A\in\Omega^p(M)$, globally F = curvature of a $U(1)$-$(p-1)$-gerbe

- 'Electric' p-form symmetry: $A\longmapsto A+\lambda$, $\lambda\in\Omega^p_{\rm cl}(M)$
  Global $U(1)_e$ symmetry for $\lambda\in\Omega^p_{\rm cl}(M)/\mathrm{d}\Omega^{p-1}(M)\simeq H^p(M,\mathbb{R})$
- Conserved $(p+1)$-form current: $J = F$, $\mathrm{d}*J = \mathrm{d}*F = 0$
- Codimension $(p+1)$ topological operator: $U_\alpha[\Sigma] = \exp(\,\mathrm{i}\,\alpha\int_\Sigma *J)$
- Charge objects are 'Wilson' operators $W_\ell[L] = \exp(\,\mathrm{i}\,\ell\int_L A)$ for $L\subset M$ closed with $\dim L = p$
  Deforming symmetry defect $U_\alpha[\Sigma]$ past $W_\ell[L]$ results in a phase:

$$U_\alpha[\Sigma]\,W_\ell[L] = \mathrm{e}^{\,\mathrm{i}\,\alpha\,\ell\,\mathrm{lk}(\Sigma,L)}\,W_\ell[L]$$

Generalized Abelian Gauge Theories

- Dual global 'magnetic' $(d-p-2)$-form symmetry $U(1)_m$ with conserved $(d-p-1)$-form current: $\widetilde{J} = *F \ , \ \mathrm{d}*\widetilde{J} = \mathrm{d}F = 0$

- Codim $(d-p-1)$ topological operators: $U_{\widetilde{\alpha}}[\widetilde{\Sigma}] = \exp(\,\mathrm{i}\,\widetilde{\alpha} \int_{\widetilde{\Sigma}} *\widetilde{J}\,)$

- Charged objects are ''t Hooft' operators $\widetilde{U}_{\widetilde{\ell}}[\widetilde{L}]$ for $\widetilde{L} \subset M$ closed with $\dim \widetilde{L} = (d-p-2)$:

$$\widetilde{U}_{\widetilde{\alpha}}[\widetilde{\Sigma}]\,\widetilde{W}_{\widetilde{\ell}}[\widetilde{L}] = \mathrm{e}^{\,\mathrm{i}\,\widetilde{\alpha}\,\widetilde{\ell}\,\mathrm{lk}(\widetilde{\Sigma},\widetilde{L})}\,\widetilde{W}_{\widetilde{\ell}}[\widetilde{L}]$$

- **Note:** Total higher form symmetry is **not** $U(1)_e \times U(1)_m$ when there is torsion in $H^\bullet(M,\mathbb{Z})$, because torsion link pairing yields noncommutative topological operators

(Freed, Moore & Segal '06; Becker, Benini, Schenkel & Sz '15)

Anomaly Field Theories

- Expectation: Any generalised global symmetry G with a 't Hooft anomaly is described by a TQFT, the anomaly field theory — an invertible relative QFT (Freed & Teleman '12; Freed '14)

- Remedies anomaly by "coupling" d-dimensional theory with symmetry G to $(d+1)$-dimensional anomaly field theory such that the contributions of gauge transformations cancel each other: *anomaly inflow* or *edge modes*

- Generalized abelian gauge theories have a mixed 't Hooft anomaly: it is not possible to simultaneously gauge the electric $(F \longmapsto F - B)$ and magnetic $(\widetilde{B} \wedge F)$ higher form symmetries

- Regard the original theory as sitting on the boundary of a $(d+1)$-dimensional manifold X with $\partial X = M$

  The anomaly is then cancelled by an anomaly inflow from the bulk classical theory, such that the bulk+boundary theory is gauge invariant

- Conversely, starting from the bulk TQFT on X, the theory on $M = \partial X$ should follow by carefully imposing boundary conditions on the fields

Anomaly Field Theories for Dual Gauge Fields

- We'll do this in a slightly different setting than usual, which lifts the dichotomy between electric and magnetic descriptions/symmetries of the same theory — close relative of SymTFT (Schenkel & Sz '??)

- Lift generalized electric-magnetic duality of higher abelian gauge theory to pullback $\mathcal{C}^{p+1}(M,\mathbb{Z})$ in differential cohomology:

$$\begin{array}{ccc} \mathcal{C}^{p+1}(M,\mathbb{Z}) & \dashrightarrow & \hat{H}^{d-p-1}(M) \\ \downarrow & & \downarrow {\scriptstyle *\,\widetilde{F}} \\ \hat{H}^{p+1}(M) & \xrightarrow[F]{} & \Omega^{p+1}(M) \end{array}$$

$(F,\widetilde{F}) \ = \ $ curvatures of $\big((p-1)$-gerbe , $(d-p-2)$-gerbe$\big)$ such that $F \ = \ *\,\widetilde{F}$, $\mathrm{d}F \ = \ 0 \ = \ \mathrm{d}\widetilde{F}$; implies equation of motion $\mathrm{d} * F \ = \ 0$

(Freed, Moore & Segal '06; Becker, Benini, Schenkel & Sz '15)

- Illustration: Anomaly field theory for semi-classical configuration space $\mathcal{C}^2(M,\mathbb{Z})$ of dual gauge fields for Maxwell theory $(p=1)$ in $d=4$

2-BF Theory

$$\mathcal{S}(B,\widetilde{B}) \;=\; \frac{1}{2}\int_X \widetilde{B}\wedge \mathrm{d}B - B\wedge \mathrm{d}\widetilde{B}$$

$X \;=\;$ oriented 5-manifold with $\partial X \;=\; M \;=\;$ 4-manifold with metric

$B,\widetilde{B}\in\Omega^2(X)$; reduces to the standard higher BF action when $\partial X \;=\; \varnothing$

- 1-gauge transformations: $(\Lambda,\widetilde{\Lambda}):(B,\widetilde{B})\longrightarrow(B+\mathrm{d}\Lambda,\widetilde{B}+\mathrm{d}\widetilde{\Lambda})$ with $(\Lambda,\widetilde{\Lambda})\in\Omega^1(X)\times\Omega^1(X)$

- 2-gauge transformations: $(\varepsilon,\widetilde{\varepsilon}):(\Lambda,\widetilde{\Lambda})\Longrightarrow(\Lambda+\mathrm{d}\varepsilon,\widetilde{\Lambda}+\mathrm{d}\widetilde{\varepsilon})$ with $(\varepsilon,\widetilde{\varepsilon})\in\Omega^0(X)\times\Omega^0(X)$

- Action is **not** gauge-invariant:

$$\mathcal{S}(B+\mathrm{d}\Lambda,\widetilde{B}+\mathrm{d}\widetilde{\Lambda}) \;=\; \mathcal{S}(B,\widetilde{B})+\frac{1}{2}\int_M \mathrm{d}\widetilde{\Lambda}\wedge B-\mathrm{d}\Lambda\wedge\widetilde{B}$$

Configuration 2-Groupoid for 2-BF Theory

$\mathscr{F}(X) \ = \ $ 2-groupoid of strictly boundary conditioned fields on X with

- Objects: $(B,\widetilde{B})\in\Omega^2(X)\times\Omega^2(X)$ such that $\widetilde{B} \ = \ *B$ on M
- 1-morphisms: $(\Lambda,\widetilde{\Lambda}):(B,\widetilde{B})\longrightarrow(B+\mathrm{d}\Lambda,\widetilde{B}+\mathrm{d}\widetilde{\Lambda})$ with $(\Lambda,\widetilde{\Lambda})\in\Omega^1(X)\times\Omega^1(X)$ such that $\Lambda \ = \ 0 \ = \ \widetilde{\Lambda}$ on M
- 2-morphisms: $(\varepsilon,\widetilde{\varepsilon}):(\Lambda,\widetilde{\Lambda})\Longrightarrow(\Lambda+\mathrm{d}\varepsilon,\widetilde{\Lambda}+\mathrm{d}\widetilde{\varepsilon})$ with $(\varepsilon,\widetilde{\varepsilon})\in\Omega^0(X)\times\Omega^0(X)$ such that $\varepsilon \ = \ 0 \ = \ \widetilde{\varepsilon}$ on M

Then $\mathcal{S}:\mathscr{F}(X)\longrightarrow\mathbb{R}$ is a gauge-invariant function on this 2-groupoid

Note: $\mathscr{F}(X)$ is a strict pullback (in the category of 2-groupoids), which is equivalent to the homotopy pullback $\mathscr{F}_{\mathrm{ho}}(X)$ (Hollander '07)

$\Longrightarrow$ We can equivalently implement the boundary condition 'weakly' by a homotopy pullback of 2-groupoids

Edge Modes for 2-BF Theory

$\mathscr{F}_{\text{ho}}(X) \;\simeq\;$ 2-groupoid of weakly boundary conditioned fields on X with

- Objects: $(B, \widetilde{B}, A, \widetilde{A}) \in \Omega^2(X)^{\times 2} \times \Omega^1(M)^{\times 2}$ such that

$$\widetilde{B} - \mathrm{d}\widetilde{A} \;=\; *\,(B - \mathrm{d}A) \quad \text{on } M$$

- 1-morphisms:

$$(\Lambda, \widetilde{\Lambda}, \lambda, \widetilde{\lambda}) : (B, \widetilde{B}, A, \widetilde{A}) \longrightarrow (B + \mathrm{d}\Lambda\,,\; \widetilde{B} + \mathrm{d}\widetilde{\Lambda}\,,\; A + \Lambda - \mathrm{d}\lambda\,,\; \widetilde{A} + \widetilde{\Lambda} - \mathrm{d}\widetilde{\lambda})$$

with $(\Lambda, \widetilde{\Lambda}, \lambda, \widetilde{\lambda}) \in \Omega^1(X)^{\times 2} \times \Omega^0(M)^{\times 2}$

- 2-morphisms:

$$(\varepsilon, \widetilde{\varepsilon}) : (\Lambda, \widetilde{\Lambda}, \lambda, \widetilde{\lambda}) \Longrightarrow (\Lambda + \mathrm{d}\varepsilon\,,\; \widetilde{\Lambda} + \mathrm{d}\widetilde{\varepsilon}\,,\; \lambda + \varepsilon\,,\; \widetilde{\lambda} + \widetilde{\varepsilon})$$

with $(\varepsilon, \widetilde{\varepsilon}) \in \Omega^0(X) \times \Omega^0(X)$

Edge Modes for 2-BF Theory

- Equivalence implemented by 2-functor $\Psi : \mathscr{F}(X) \xrightarrow{\simeq} \mathscr{F}_{\rm ho}(X)$ with

$$\Psi(B,\widetilde{B}) \ = \ (B,\widetilde{B},0,0) \quad , \quad \Psi(\Lambda,\widetilde{\Lambda}) \ = \ (\Lambda,\widetilde{\Lambda},0,0) \quad , \quad \Psi(\varepsilon,\widetilde{\varepsilon}) \ = \ (\varepsilon,\widetilde{\varepsilon})$$

- Essential surjectivity:

$$(A,\widetilde{A},0,0) : \Psi(B-\mathrm{d}A,\widetilde{B}-\mathrm{d}\widetilde{A}) \longrightarrow (B,\widetilde{B},A,\widetilde{A})$$

- Transfering $\mathcal{S} : \mathscr{F}(X) \longrightarrow \mathbb{R}$ along equivalence $\Psi : \mathscr{F}(X) \xrightarrow{\simeq} \mathscr{F}_{\rm ho}(X)$ gives gauge-invariant action $\mathcal{S}^{\rm ext} : \mathscr{F}_{\rm ho}(X) \longrightarrow \mathbb{R}$ extended by edge modes:

$$\mathcal{S}^{\rm ext}(B,\widetilde{B};A,\widetilde{A}) \ = \ \mathcal{S}(B-\mathrm{d}A,\widetilde{B}-\mathrm{d}\widetilde{A})$$

$$= \ \frac{1}{2}\int_X \big(\widetilde{B}\wedge\mathrm{d}B - B\wedge\mathrm{d}\widetilde{B}\big) - \frac{1}{2}\int_M F\wedge*(F-B) + B\wedge\widetilde{F}]$$

where $F \ = \ \mathrm{d}A$, $\widetilde{F} \ = \ \mathrm{d}\widetilde{A}$, and $\widetilde{B}-\widetilde{F} \ = \ *(B-F)$ on M

- Recovers Maxwell action $-\frac{1}{2}\int_M F\wedge *F$ for $B=0$, with $\widetilde{F} \ = \ *F \Longrightarrow (A,\widetilde{A})\in\Omega^1(M)\times\Omega^1(M)$ are dual gauge fields