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# List of Statements

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# Glossary of Notation

## Operations and Symbols

| | |
|---|---|
| $:=$ and $=:$ | equal by definition |
| $\equiv$ | identically equal |
| $^*$ | indication of some dual/adjoint/polar operation |
| $\langle\cdot,\cdot\rangle$ | canonical pairing between space $X$ and its topological dual $X^*$ |
| $x \to \bar{x}$ | $x$ converges to $\bar{x}$ strongly (by norm) |
| $x \stackrel{w}{\to} \bar{x}$ | $x$ converges to $\bar{x}$ weakly (in weak topology) |
| $x \stackrel{w^*}{\to} \bar{x}$ | $x$ converges to $\bar{x}$ weak$^*$ (in weak$^*$ topology) |
| $x \stackrel{\Omega}{\to} \bar{x}$ | $x$ converges to $\bar{x}$ with $x \in \Omega$ |
| $\liminf$ | lower limit for real numbers |
| $\limsup$ | upper limit for real numbers |
| $\operatorname{Lim\,inf}$ | lower/inner limit for set-valued mappings |
| $\operatorname{Lim\,sup}$ | upper/outer limit for set-valued mappings |
| $\dim X$ and $\operatorname{codim} X$ | dimension and codimension of $X$, respectively |
| $\prec$ | preference relation |
| $\|\cdot\|$ or $|\cdot|$ or $|||\cdot|||$ | norms |
| $\operatorname{haus}(\Omega_1, \Omega_2)$ | Pompieu-Hausdorff distance between sets |
| $\operatorname{lip} F(\bar{x}, \bar{y})$ | exact Lipschitzian bound of $F$ around $(\bar{x}, \bar{y})$ |
| $\operatorname{reg} F(\bar{x}, \bar{y})$ | exact metric regularity bound of $F$ around $(\bar{x}, \bar{y})$ |
| $\operatorname{cov} F(\bar{x}, \bar{y})$ | exact covering/linear openness bound of $F$ around $(\bar{x}, \bar{y})$ |
| $\operatorname{rad} F(\bar{x}, \bar{y})$ | radius of metric regularity of $F$ around $(\bar{x}, \bar{y})$ |
| $\triangle$ | end of proof |

## Spaces

| | |
|---|---|
| $I\!R := (-\infty, \infty)$ | real line |
| $\overline{I\!R} := [-\infty, \infty]$ | extended real line |
| $I\!R^n$ | $n$-dimensional Euclidean space |
| $I\!R^n_+$ and $I\!R^n_-$ | nonnegative and nonpositive orthant of $I\!R^n$, respectively |

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| | |
|---|---|
| $\mathcal{C}([a,b];X)$ | space of $X$-valued continuous mappings with the supremum norm on $[a,b]$ |
| $\mathcal{C}(K)$ | space of continuous functions on the compact set $K$ |
| $\mathcal{C}[0,\omega_1]$ | continuous functions on $[0,\omega_1]$, where $\omega_1$ is the first uncountable ordinal |
| $\mathcal{C}_0$ | continuous functions with compact supports |
| $\mathcal{C}^k$, $1 \le k \le \infty$, | $k$ times differentiable functions with all continuous derivatives |
| $\mathcal{C}^{1,1}$ | continuously differentiable functions with Lipschitzian derivatives |
| $L^p([a,b];X)$, $1 \le p \le \infty$, | standard Lebesgue spaces of $X$-valued mappings |
| $W^{1,p}$ and $H^p$ | standard Sobolev spaces |
| $\mathcal{M}$ and $\mathcal{M}_b$ | measure spaces (dual to spaces of continuous functions) |
| $BV$ | functions of bounded variation |
| $c$ | space of real number sequences with the supremum norm |
| $c_0$ | subspace of $c$ with sequences converging to zero |
| $\ell^p$, $1 \le p \le \infty$, | sequences of real numbers with standard $p$–norms |

**Sets**

| | |
|---|---|
| $\emptyset$ | empty set |
| $I\!N$ | set of natural numbers |
| $B_r(x)$ | ball centered at $x$ with radius $r$ |
| $I\!B_X$ | closed unit ball of space $X$ |
| $I\!B$ and $I\!B^*$ | closed unit balls of the space and duals space in question |
| $S$ and $S^*$ | unit spheres of the space and dual space in question |
| $\operatorname{int}\Omega$ and $\operatorname{ri}\Omega$ | interior and relative interior, respectively |
| $\operatorname{cl}\Omega$ and $\operatorname{cl}^*\Omega$ | closure and weak$^*$ topological closure, respectively |
| $\operatorname{bd}\Omega$ or $\partial\Omega$ | set boundary |
| $\operatorname{co}\Omega$ and $\operatorname{clco}\Omega$ | convex hull and closed convex hull, respectively |
| $\operatorname{cone}\Omega$ | conic hull |
| $\operatorname{aff}\Omega$ and $\overline{\operatorname{aff}}\,\Omega$ | affine hull and closed affine hull, respectively |
| $\operatorname{mes}\Omega$ or $\mathcal{L}^n(\Omega)$ | Lebesgue ($n$-dimensional) measure |
| $\Pi(x;\Omega)$ | projection of $x$ to $\Omega$ |
| $T(\bar{x};\Omega)$ | contingent cone to $\Omega$ at $\bar{x}$ |
| $T_W(\bar{x};\Omega)$ | weak contingent cone to $\Omega$ at $\bar{x}$ |
| $T_C(\bar{x};\Omega)$ | Clarke tangent cone to $\Omega$ at $\bar{x}$ |
| $N(\bar{x};\Omega)$ | basic/limiting normal cone to $\Omega$ at $\bar{x}$ |
| $N_+(\bar{x};\Omega(\bar{y}))$ | extended limiting normal cone to $\Omega(\bar{y})$ at $\bar{x}$ |
| $\widehat{N}(\bar{x};\Omega)$ | prenormal cone or Fréchet normal cone to $\Omega$ at $\bar{x}$ |
| $N_C(\bar{x};\Omega)$ | Clarke normal cone to $\Omega$ at $\bar{x}$ |
| $N_G(\bar{x};\Omega)$ and $\widetilde{N}_G(\bar{x};\Omega)$ | approximate $G$-normal cone and its nucleus to $\Omega$ at $\bar{x}$ |

| | |
|---|---|
| $N_P(\bar{x};\Omega)$ | proximal normal cone to $\Omega$ at $\bar{x}$ |
| $\widehat{N}_\varepsilon(\bar{x};\Omega)$ | sets of $\varepsilon$-normals to $\Omega$ at $\bar{x}$ |
| $S_\varepsilon(\bar{x};\Omega)$ | $\varepsilon$-support to $\Omega$ at $\bar{x}$ |

**Functions**

| | |
|---|---|
| $\delta(\cdot;\Omega)$ | set indicator function |
| $\mathrm{dist}(\cdot;\Omega)$ or $d_\Omega(\cdot)$ | distance function |
| $\rho(x,y) := \mathrm{dist}(y;F(x))$ | extended distance function |
| $\mathrm{dom}\,\varphi$ | domain of $\varphi\colon X \to \overline{I\!R}$ |
| $\mathrm{epi}\,\varphi$, $\mathrm{hypo}\,\varphi$, and $\mathrm{gph}\,\varphi$ | epigraph, hypergraph, and graph of $\varphi$, respectively |
| $x \xrightarrow{\varphi} \bar{x}$ | $x \to \bar{x}$ with $\varphi(x) \to \varphi(\bar{x})$ |
| $\mathcal{H}$ | Hamiltonian function in optimal control |
| $H$ | Hamilton-Pontryagin function in optimal control |
| $L$ | Lagrangian function in optimization |
| $L_\Omega$ | essential Lagrangian relative to $\Omega$ |
| $\tau(F;h)$ | averaged modulus of continuity |
| $\varphi'(\bar{x})$ or $\nabla\varphi(\bar{x})$ | Fréchet derivative/gradient of $\varphi$ at $\bar{x}$ |
| $\varphi'_\beta(\bar{x})$ or $\nabla_\beta\varphi(\bar{x})$ | derivative/gradient of $\varphi$ at $\bar{x}$ with respect to some bornology |
| $\lvert\nabla\varphi\rvert(\bar{x})$ | (strong) slope of $\varphi$ at $\bar{x}$ |
| $\varphi'(\bar{x};v)$ | classical directional derivative of $\varphi$ at $\bar{x}$ in direction $v$ |
| $\varphi^\circ(\bar{x};v)$ and $\varphi^\uparrow(\bar{x};v)$ | generalized directional derivative and subderivative of $\varphi$ |
| $d^-\varphi(\bar{x};v)$ and $d^+\varphi(\bar{x};v)$ | Dini-Hadamard lower and upper directional derivative of $\varphi$ |
| $\partial\varphi(\bar{x})$ | basic/limiting subdifferential of $\varphi$ at $\bar{x}$ |
| $\partial^+\varphi(\bar{x})$ | upper subdifferential of $\varphi$ at $\bar{x}$ |
| $\partial^0\varphi(\bar{x})$ | symmetric subdifferential of $\varphi$ at $\bar{x}$ |
| $\partial_\geq\varphi(\bar{x})$ | right-sided subdifferential of $\varphi$ at $\bar{x}$ |
| $\partial^\infty\varphi(\bar{x})$ | singular subdifferential of $\varphi$ at $\bar{x}$ |
| $\widehat{\partial}\varphi(\bar{x})$ and $\widehat{\partial}^+\varphi(\bar{x})$ | Fréchet subdifferential and upper subdifferential of $\varphi$ at $\bar{x}$, respectively |
| $\partial_A\varphi(\bar{x})$ and $\partial_G\varphi(\bar{x})$ | approximate $A$-subdifferential and $G$-subdifferential of $\varphi$ at $\bar{x}$ |
| $\partial_C\varphi(\bar{x})$ | Clarke subdifferential/generalized gradient of $\varphi$ at $\bar{x}$ |
| $\partial_\beta\varphi(\bar{x})$ | viscosity (bornological) $\beta$-subdifferential of $\varphi$ at $\bar{x}$ |
| $\partial_P\varphi(\bar{x})$ | proximal subdifferential of $\varphi$ at $\bar{x}$ |
| $\widehat{\partial}_\varepsilon\varphi(\bar{x})$, $\widehat{\partial}_{a\varepsilon}\varphi(\bar{x})$, and $\widehat{\partial}_{g\varepsilon}\varphi(\bar{x})$ | Fréchet-type $\varepsilon$-subdifferentials of $\varphi$ at $\bar{x}$ |
| $\partial^-_\varepsilon\varphi(\bar{x})$ | Dini $\varepsilon$-subdifferential of $\varphi$ at $\bar{x}$ |
| $\nabla^2\varphi(\bar{x})$ | classical Hessian (matrix of second derivatives if in $I\!R^n$) of $\varphi$ at $\bar{x}$ |
| $\partial^2\varphi$, $\partial^2_N\varphi$, and $\partial^2_M\varphi$ | second-order subdifferentials (generalized Hessians) of $\varphi$ |

**Mappings**

| | |
|---|---|
| $f: X \to Y$ | single-valued mappings from $X$ to $Y$ |
| $F: X \rightrightarrows Y$ | set-valued mappings from $X$ to $Y$ |
| $\operatorname{dom} F$ | domain of $F$ |
| $\operatorname{rge} F$ | range of $F$ |
| $\operatorname{gph} F$ | graph of $F$ |
| $\ker F$ | kernel of $F$ |
| $F^{-1}: Y \rightrightarrows X$ | inverse mapping to $F: X \rightrightarrows Y$ |
| $F(\Omega)$ and $F^{-1}(\Omega)$ | image and inverse image/preimage of $\Omega$ under $F$ |
| $F \circ G$ | composition of mappings |
| $F \overset{h}{\circ} G$ | $h$-composition of mappings |
| $\Delta(\cdot; \Omega)$ | set indicator mapping |
| $\Omega_\rho$ | set enlargement mapping |
| $E_\varphi$ | epigraphical mapping |
| $\mathcal{E}(f, \Theta)$ | generalized epigraph of $f: X \to Y$ with respect to $\Theta \subset Y$ |
| $DF(\bar{x}, \bar{y})$ | graphical/contingent derivative of $F$ at $(\bar{x}, \bar{y}) \in \operatorname{gph} F$ |
| $D^*F(\bar{x}, \bar{y})$ | (basic) coderivative of $F$ at $(\bar{x}, \bar{y}) \in \operatorname{gph} F$ |
| $D^*_N F(\bar{x}, \bar{y})$ | normal coderivative of $F$ at $(\bar{x}, \bar{y}) \in \operatorname{gph} F$ |
| $D^*_M F(\bar{x}, \bar{y})$ and $\widetilde{D}^*_M F(\bar{x}, \bar{y})$ | mixed and reversed mixed coderivative of $F$ at $(\bar{x}, \bar{y})$, respectively |
| $\widehat{D}^* F(\bar{x}, \bar{y})$ and $\widehat{D}^*_\varepsilon F(\bar{x}, \bar{y})$ | Fréchet coderivative and $\varepsilon$-coderivative of $F$ at $(\bar{x}, \bar{y})$, respectively |
| $Jf(\bar{x})$ | generalized Jacobian of $f$ at $\bar{x}$ |
| $\Lambda f(\bar{x})$ | derivate container of $f$ at $\bar{x}$ |

# Subject Index



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