M0 @PGPname[†1]

†1 transfer to end for full

time at day 01 tuesday, month 02 february, year 2011, hour 10:00 before noon, at place court 505

time at day 01 tuesday, month 02 february, year 2011, hour 23:59 after noon, at place http://mathim.com/ct

touch last of data at day 31 monday, month 01 january, year 2011, hour 15:58 after noon

Short: (on CHIC 05) how duality?

1. Import. Import reference for all for now until far time:

[tourlakis1] author_George Tourlakis_ short_Lectures in Logic and Set Theory_ refer_Cambridge University Press, (2003), Volume 1, Cambridge studies in advanced mathematics 82_

[tourlakis2] author_George Tourlakis_ short_Lectures in Logic and Set Theory_ refer_Cambridge University Press, (2003), Volume 2, Cambridge studies in advanced mathematics 83_

[aigner1] author_Martin Aigner_ short_Combinatorial Theory_ refer_Springer, (1997), reprint from (1979), Classics in Mathematics_

[aigner2] author_Martin Aigner_ short_Discrete mathematics_ refer_Springer, (2007), trans-write from (2004), American Mathematical Society_

[aigner3] author_Martin Aigner_ short_A Course in Enumeration_ refer_Springer, (2007), Graduate Texts in Mathematics 238_

[borceux1] author_Francis Borceux_ short_Handbook of Categorical Algebra 1_ refer_Cambridge University Press, (1994), Encyclopedia Of Mathematics And Its Applications 50_

[borceux2] author_Francis Borceux_ short_Handbook of Categorical Algebra 2_ refer_Cambridge University Press, (1994), Encyclopedia Of Mathematics And Its Applications 51_

[borceux3] author_Francis Borceux_ short_Handbook of Categorical Algebra 3_ refer_Cambridge University Press, (1994), Encyclopedia Of Mathematics And Its Applications 52_

[gelfand] author_Sergei Izrailevich Gelfand, Yuri I. Manin_ short_Methods of Homological Algebra_ refer_Springer, (2003), Second Edition, Springer Monographs in Mathematics_

[goerss] author_Paul G. Goerss, John F. Jardine_ short_Simplicial Homotopy Theory_ refer_Birkhauser, (2009), Modern Birkhauser Classics_

2. Normal.

2.1. Prophecy. (Thm 1.3.3, ref [borceux1]) Behold internalized Set-valued functor $F : \mathscr{A} \to \mathrm{Set}$. Deduce a contrast

$$\mathrm{Nat}(\mathcal{A}[\#, -], F) \quad \text{against} \quad F\#$$

as internalization, with commutability in variable F.

Deduce. Behold $f : A \to B$ and $\gamma : F \Rightarrow G$, deduce, for all $\alpha : \mathcal{A}(A, -) \Rightarrow F$,

$$\begin{aligned} Gf\,(\gamma_A(\alpha_A(1_A))) &= Gf \circ \gamma_A \circ \alpha_A\,(1_A) \\ &= \gamma_B \circ \alpha_B \circ \mathscr{A}(A, f)\,(1_A) \\ &= \gamma_B \circ \alpha_B \circ \mathscr{A}(f, B)\,(1_B) \\ &= (\gamma \circ (\alpha \circ \mathscr{A}(f, -)))_B\,(1_B)\ . \end{aligned}$$

■

3. Duality

3.1. Prophecy. (Ex 1.10.3.b, 1.10.3.d, ref [borceux1]) There is duality $\mathrm{Set}(-, 2) : \mathrm{Set} \to \mathrm{CBA}$ with link $2 \in \mathrm{Set}, \in \mathrm{CBA}$.

There is duality $\mathrm{FAb}(-, U) : \mathrm{FAb} \to \mathrm{FAb}$ with link $U \in \mathrm{FAb}, \in \mathrm{FAb}$.

3.2. Prophecy. Behold $\mathscr{A}$ small. Deduce $\mathrm{Fun}(\mathscr{A}, \mathrm{Set})$ is a category of dualities, is the duality for $\mathscr{A}$.

Deduce. Protos, deduce (Prop 1.5.2, ref [borceux1]) the functor $Y^* : \mathscr{A}^{\mathrm{op}} \to \mathrm{Fun}(\mathscr{A}, \mathrm{Set})$, $\# \mapsto \mathscr{A}(\#, -)$ is full faithful.

Secondo, given $F : \mathscr{A} \to \mathrm{Set}$, deduce the category of (universal|non-universal) **coreflections** (copairs) of F along Y^*,

$$\{\mathscr{A}(A, -) : A \in \mathscr{A}^{\mathrm{op}}\}/F \ \cong \mathrm{Elts}(\mathrm{Nat}(\mathscr{A}[\#, -], F)) \cong \mathrm{Elts}(F)^{\mathrm{op}}\ .$$

Then deduce (Thm 2.15.6, ref [borceux1]) the **colimit**

$$\begin{aligned} &(F, (\alpha : \mathscr{A}(A, -) \Rightarrow F)_{(A,\alpha) \in \mathrm{Elts}(F)^{\mathrm{op}}}) \\ &\qquad\qquad = \mathrm{colim}_{(A,\alpha : \mathscr{A}(A,-) \Rightarrow F) \in \mathrm{Elts}(F)^{\mathrm{op}}}\, \mathscr{A}(A, -) \end{aligned}$$

Tertio, given any $Z : \mathscr{A}^{\mathrm{op}} \to \mathscr{C}$ with $\mathscr{C}$ has small colimits, deduce Z has **extension** W along Y^* with value on F as

$$(W(F), (\sigma^F_{(A,\alpha)} : ZA \to W(F))_{(A,\alpha:\mathscr{A}(A,-)\Rightarrow F)\in \mathrm{Elts}(F)^{\mathrm{op}}}) \\ = \mathrm{colim}_{(A,\alpha:\mathscr{A}(A,-)\Rightarrow F)\in \mathrm{Elts}(F)^{\mathrm{op}}} ZA$$

and $(\sigma^{\mathscr{A}(A,-)}_{(A,1_{\mathscr{A}(A,-)}:\mathscr{A}(A,-)\Rightarrow\mathscr{A}(A,-))})_{A\in\mathscr{A}^{\mathrm{op}}} : Z \Rightarrow WY^*$ is iso. ∎

4. Back to normal.

4.1. Prophecy. (Prop 4.5.14, ref [borceux1]) Behold $\mathscr{A}$ small. Write full subcategory $i : \{\mathscr{A}(A,-) : A \in \mathscr{A}\} \subseteq \mathrm{Fun}(\mathscr{A}, \mathrm{Set})$. Deduce the functor (in larger Grothendieck universe)

$$F \longmapsto \mathrm{Nat}(i(\#), F)$$

is full faithfull.

Deduce. Given $\Xi_{\mathscr{A}(A,-)} : \mathrm{Nat}(\mathscr{A}(A,-), F) \to \mathrm{Nat}(\mathscr{A}(A,-), G)$ commutable transformation in variable $\mathscr{A}(A,-)$, get another cocone $(\Xi_{\mathscr{A}(A,-)}(\alpha) : \mathscr{A}(A,-) \Rightarrow G)_{(A,\alpha:\mathscr{A}(A,-)\Rightarrow F)\in\mathrm{Elts}(F)^{\mathrm{op}}}$ of shape $\mathrm{Elts}(F)^{\mathrm{op}}$ on diagram $(\mathscr{A}(A,-))_{(A,\alpha:\mathscr{A}(A,-)\Rightarrow F)\in\mathrm{Elts}(F)^{\mathrm{op}}}$ at tip G, thus get unique $\gamma : F \Rightarrow G$ with $\gamma \circ \alpha = \Xi_{\mathscr{A}(A,-)}(\alpha)$ for all $(A, \alpha : \mathscr{A}(A,-) \Rightarrow F) \in \mathrm{Elts}(F)^{\mathrm{op}}$. ∎

5. ?[$\mathscr{A}$ algebraic | localic]

5.1. Reductions:

5.2. pre-Prophecy. (Prop 6.1.2, Prop 6.1.4, ref [borceux1]) Behold $\mathscr{A}$ with finite limits. Deduce the reduction (hold that whole commutability of filtered colimits with finite limits is not lacked)

$$F : \mathscr{A} \to \mathrm{Set} \text{ preserves finite limits } \longleftrightarrow \ \mathrm{Elts}(F)^{\mathrm{op}} \ \text{ is finitely-filtered}$$

("$\rightarrow$" holds $\mathscr{A}$ with finite limits) and the reduction to $\mathrm{Fun}(\mathscr{A}, \mathrm{Set})$:

$$F : \mathscr{A} \to \mathscr{B} \text{ preserves finite limits} \\ \longleftrightarrow \ \forall B \in \mathscr{B} \quad \mathrm{Elts}(\mathscr{B}(B, F-) : \mathscr{A} \to \mathrm{Set})^{\mathrm{op}} \ \text{ is finitely-filtered}$$

("$\rightarrow$" holds $\mathscr{A}$ with finite limits).

5.3. pre-Prophecy. (Exe 3.9.2, ref [borceux1]) Deduce the reduction to $\mathrm{Fun}(\mathscr{A}, \mathrm{Set})$:

$$F : \mathscr{A} \to \mathscr{B} \text{ has a left adjoint} \\ \longleftrightarrow \ \forall B \in \mathscr{B}, \quad \mathscr{B}(B, F-) : \mathscr{A} \to \mathrm{Set} \text{ is representable} \\ \text{(some orthogonality) } \theta_{-,B} : \mathscr{A}(|G|B, -) \cong \mathscr{B}(B, F-) \ .$$

5.4. $\mathscr{A}$ algebraic:

5.5. Prophecy. (Ex 5.2.2.c, ref [borceux2]) If $\mathscr{A}$ small with finite limits (saturated), able to name $\mathrm{Lex}(\mathscr{A}, \mathrm{Set})$ locally finitely-presentable.

5.6. Prophecy. (Prop 3.8.12, Thm 5.2.7, ref [borceux2]) If $\mathscr{M}$ locally finitely-presentable category (for example, of algebras $\mathrm{Mod}_{\mathcal{T}}$ with $\mathcal{T} = \{T^0, T^1, \ldots, T^n, \ldots\}$ non-saturated), deduce small, stable under finite limits (saturated, dense) $\mathscr{A}$ with $\mathscr{A}^{\mathrm{op}}$ equivalent to the full subcategory of $\mathscr{M}$ of all finitely-presentable objects and with $\mathscr{M}$ is equivalent to $\mathrm{Lex}(\mathscr{A}, \mathrm{Set})$.

5.7. $\mathscr{A}$ localic:

5.8. Prophecy. (Sec 3.3, Prop 3.4.16, ref [borceux3]) Behold $\mathscr{A}$ small. If $\mathscr{A}$ localic with (transfinitely built Grothendieck saturated) coverings $\mathcal{L}$, deduce able to name flat (exact) orthogonal subcategory $\Sigma\Sigma \dashv i : \mathrm{Sh}(\mathscr{A}^{\mathrm{op}}, \mathcal{L}) \subseteq \mathrm{Fun}(\mathscr{A}^{\mathrm{op}}, \mathrm{Set})$ with $\eta_F^C : F(C) \subseteq \Sigma(F)(C) = \mathrm{colim}_{R \in \mathcal{L}(C)} \mathrm{Nat}(R, F)$ and with $(\Sigma\Sigma(\mathscr{A}(\#, A)))_{A \in \mathscr{A}}$ family of finitely-presentable generators in $\mathrm{Sh}(\mathscr{A}, \mathcal{L})$.

5.9. Prophecy. (Prop 3.5.4, ref [borceux3]) Behold $\mathscr{A}$ small. If $\mathscr{M}$ flat (exact) orthogonal subcategory of $\mathrm{Fun}(\mathscr{A}^{\mathrm{op}}, \mathrm{Set})$, deduce localic $\mathscr{A}$ with (Grothendieck saturated) coverings $\mathcal{L}$ with $\mathscr{M} = \mathrm{Sh}(\mathscr{A}, \mathcal{L})$.

5.10. Search|query|question. ?[coherence in functor categories], then ?[algebraic|localic].

6. Other, non-ordered.

6.1. Th. 2.8.1. limits = products + equalizers: Given $\mathscr{D}$ small, diagram $F : \mathscr{D} \to \mathscr{C}$ and product $(p'_D : \prod_{D \in \mathscr{D}_0} FD \to FD)_{D \in \mathscr{D}_0}$, deduce $(M, (p'_D m : M \to FD)_{D \in \mathscr{D}_0})$ is cone on $F \quad \longleftrightarrow \quad (M, m : M \to \prod_{D \in \mathscr{D}_0} FD)$ is cone on parallel pair $\langle p'_{t(f)} \rangle_{f \in \mathscr{D}_1}, \langle Ff \circ p'_{s(f)} \rangle_{f \in \mathscr{D}_1} \colon \prod_{D \in \mathscr{D}_0} FD \rightrightarrows \prod_{f \in \mathscr{D}_1} F(t(f))$.

6.2. Prop. 2.8.2. finite limits = 1 + binary products + equalizers, and binary products + equalizers = binary products + pullbacks.

6.3. Prop. 2.9.4. $\mathscr{C}(C, -)$ preserves limits: Given diagram $F : \mathscr{D} \to \mathscr{C}$ and $q_D(m) : C \longrightarrow FD$ commutable in variable D, deduce factorization through limit $(p_D : L \to FD)_{D \in \mathscr{D}}$ of F as $\quad \forall m \quad q_D(m) : C \overset{\exists!\, q(m)}{\longrightarrow} L \overset{p_D}{\longrightarrow} FD$.

6.4. Prop. 2.9.9. $F : \mathscr{A} \subseteq \mathscr{B}$ full faithful $\quad \to \quad$ "$\exists!$" is liftable, so reflects limitativeness of cones in $\mathscr{A}$.

6.5. Sec 2.10. Absolute colimitativeness = colimitativeness is equational enough for all functors.

6.6. Sec 2.11. Final functors = concentration|reduction of whole limitativeness to limitativeness on the final part of any diagram.

6.7. Prop 2.12.1 Commutability of limits: Behold $\mathscr{A}$ complete and $\mathscr{C}, \mathscr{D}$ small and $F : \mathscr{C} \times \mathscr{D} \to \mathscr{A}$. Protos, refer to 6.10 below or Sec 2.14 ref [borceux1]. Deduce

$$\lim_C \lim_D F(C, D) = \Big(\mathrm{tip} \lim_C \lim_D^{\mathscr{A}} F(C, D),$$
$$\mathrm{tip} \lim_C \lim_D^{\mathscr{A}} F(C, D) \underset{\mathrm{proj}_C^{\lim_D F[-,D]}}{\longrightarrow} \lim_D F(C, D)\Big)$$

$$\overset{\sim}{\longleftarrow} \Big(\lim_D^{\mathscr{A}} \mathrm{tip} \lim_C F(C, D),$$
$$\lim_D^{\mathscr{A}} \mathrm{tip} \lim_C F(C, D) \underset{\lim_D \mathrm{proj}_C^{F(-,D)}}{\longrightarrow} \lim_D F(C, D)\Big)$$

with

$$\Big(\mathrm{tip}\, \mathrm{tip} \lim_C \lim_D^{\mathscr{A}} F(C, D),$$
$$\mathrm{tip}\, \mathrm{tip} \lim_C \lim_D^{\mathscr{A}} F(C, D) \underset{\mathrm{tip}\, \mathrm{proj}_C^{\lim_D F[-,D]}}{\longrightarrow} \mathrm{tip} \lim_D F(C, D) \underset{\mathrm{proj}_D^{F(C,\#)}}{\longrightarrow} F(C, D)\Big)$$

$$\overset{\sim}{\longrightarrow} \Big(\mathrm{tip} \lim_C \mathrm{tip} \lim_D F(C, D),$$
$$\mathrm{tip} \lim_C \mathrm{tip} \lim_D F(C, D) \underset{\mathrm{proj}_C^{\mathrm{tip} \lim_D F(-,D)}}{\longrightarrow} \mathrm{tip} \lim_D F(C, D) \underset{\mathrm{proj}_D^{F(C,\#)}}{\longrightarrow} F(C, D)\Big)$$

6.8. Prop 2.13.4 Commutability of finitely-filtered colimits with finite limits for all functors. Behold small filtered $\mathscr{C}$ and finite $\mathscr{D}$ and $F : \mathscr{C} \times \mathscr{D} \to \mathrm{Set}$. Deduce

$$\mathrm{colim}_C \lim_D F(C, D) = \Big(\lim_D F(C, D) \underset{\mathrm{inj}^{\lim_D F[-,D]}}{\longrightarrow} \mathrm{tip}\, \mathrm{colim}_C \lim_D F(C, D),$$
$$\mathrm{tip}\, \mathrm{colim}_C \lim_D F(C, D)\Big)$$

$$\overset{\sim}{\longrightarrow} \Big(\lim_D F(C, D) \underset{\lim_D \mathrm{inj}_C^{F(-,D)}}{\longrightarrow} \lim_D \mathrm{tip}\, \mathrm{colim}_C F(C, D),$$
$$\lim_D \mathrm{tip}\, \mathrm{colim}_C F(C, D)\Big)$$

6.9. Sec 2.14. Universal colimitativeness = preservation of colimitativeness after pullback at the tip.

6.10. Prop 2.15.1 Commutability of evaluation with limit: Hold that evaluation $\mathrm{ev}(?,-)$, with $\mathrm{ev}(F,x) = Fx$, F functor, x object or arrow, is able to act on cones substituted for both variables. Behold $F : \mathscr{D} \to \mathrm{Fun}(\mathscr{C},\mathscr{A})$ with $\mathscr{C}$ and $\mathscr{D}$ small. Deduce

$$\Big(\lim_{D\in\mathscr{D}}\left(F(D)\right)\Big)(-) = \lim_{D\in\mathscr{D}}\Big(F(D)[-]\Big)$$

if any one side is present.

6.11. Prop 2.15.5. $\quad Y_* : - \mapsto \mathscr{C}(\#,-) \quad$ preserves limits.

6.12. Prop 3.3.1. Behold $F : \mathscr{A} \to \mathscr{B}$ and $B \in \mathscr{B}$. Deduce

$$\exists\,\alpha : B \to FL \quad \text{with} \quad \Big((L,\alpha),(p_{(A,b)} : (L,\alpha) \to (A,b))_{(A,b)\in\mathrm{Elts}(\mathscr{B}(B,F-))}\Big)$$

if and only if

$$\Big(L,(p_{(A,b)} : L \to A)_{(A,b)\in\mathrm{Elts}(\mathscr{B}(B,F-))}\Big) \quad \text{is limit and}$$

$$\Big(FL,(Fp_{(A,b)} : FL \to FA)_{(A,b)\in\mathrm{Elts}(\mathscr{B}(B,F-))}\Big) \quad \text{is limit.}$$

6.13. Prop 3.4.1. Behold $G \dashv F : \mathscr{A} \to \mathscr{B}$ with $\varepsilon : GF \to 1_{\mathscr{A}}$. Deduce

$$\begin{aligned} F \text{ full faithfull} \quad &\to \quad F\varepsilon_A \circ FF^{-1}\eta_{FA} = F1_A \text{ and} \\ &\qquad F(F^{-1}\eta_{FA} \circ \varepsilon_A) \circ \eta_{FA} = \eta_{FA}, \\ &\leftrightarrow \quad \varepsilon_A \text{ iso} \end{aligned}$$

and

$$\varepsilon \text{ iso} \quad \to \quad F_{A,A'} = \theta_{A',FA} \circ \mathscr{A}(\varepsilon_A, A') \text{ bijection.}$$

6.14. Prop 3.5.3. Behold $r \dashv i : \mathscr{A} \subseteq \mathscr{B}$ full faithfull. Deduce if $H : \mathscr{D} \to \mathscr{A}$ and $(L,(p_D : L \to HD)_{D\in\mathscr{D}})$ limit in $\mathscr{B}$, then the iso $\eta_L^{-1} : rL \to L$ is held as factorization, then reflect limitativeness in $\mathscr{B}$ to limitativeness in $\mathscr{A}$.

6.15. Prop 3.5.4. Behold $r \dashv i : \mathscr{A} \subseteq \mathscr{B}$ full faithfull. Deduce if $H : \mathscr{D} \to \mathscr{A}$ and $(L,(s_D : HD \to L)_{D\in\mathscr{D}})$ colimit in $\mathscr{B}$, then reflect colimitative cocone in $\mathscr{B}$ to get $(rL,(rs_D \circ \varepsilon_{HD}^{-1} : HD \xrightarrow{\sim} rHD \longrightarrow rL)_{D\in\mathscr{D}})$ colimitative cocone in $\mathscr{A}$.

6.16. Prop 3.7.5. Behold $F : \mathscr{A} \to 1$ and $G : \mathscr{A} \to \mathscr{C}$, arbitrary $\mathscr{A}$. Hold $\mathrm{Fun}(1,\mathscr{C}) = \Big(\{\Delta L : L \in \mathscr{C}\},\{\Delta f \mid f : L \to L' \text{ in } \mathscr{C}\}\Big)$. Deduce colimitative cocone $(\Delta L,\alpha : G \to \Delta L)$ on G is left Kan extension of G along F.

6.17. Prop 3.7.6. Deduce

$$F : \mathscr{A} \to \mathscr{B} \text{ (of small categories) has right adjoint } G \qquad \longleftrightarrow \qquad \forall L : \mathscr{A} \to \mathscr{C} \quad \mathrm{Lan}_F L \text{ exists and } L \circ \mathrm{Lan}_F 1_{\mathscr{A}} = \mathrm{Lan}_F L$$

because of rewrite

$$(\exists G)(\exists \eta : 1_{\mathscr{A}} \to GF)\Big(\forall A \quad (FA, \eta_A) \text{ initial pair of } A \text{ along } G \quad\Big),$$
$$\longleftrightarrow \quad \exists\, (G, \eta : 1_{\mathscr{A}} \to GF)\Big((G, \eta) \text{ is initial pair of } 1_{\mathscr{A}} \text{ along } {}^*F \text{ and } \forall L : \mathscr{A} \to \mathscr{C} \quad (LG, L\eta) \text{ is initial pair of } L \text{ along } {}^*F\Big)\ .$$

6.18. Th. 3.7.2. Behold $F : \mathscr{A} \to \mathscr{B}$, $G : \mathscr{A} \to \mathscr{C}$ with $\mathscr{A}$ small, $\mathscr{C}$ cocomplete. Deduce left Kan extension K of G as $(KB, (s^B_{(A,b)} : GA \to KB)_{(A.b)\in \mathrm{Elts}(\mathscr{B}(F\#,B))})$ colimit on $(GA)_{(A,b)\in\mathrm{Elts}(\mathscr{B}(F\#,B))}$ with $(s^{FA}_{(A,1_{FA})} : GA \to KFA)_{A\in\mathscr{A}} : G \Rightarrow KF$. If F full faithful, deduce $((A, 1_{FA}), (p_{(A',b)} : (A', b) \to (A, b))_{(A',b)\in\mathrm{Elts}(\mathscr{B}(F\#,FA))})$ is terminal and $s^{FA}_{(A,1_{FA})} = Gp_{(A,1_{FA})} = 1_{GA}$ is iso.


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