leroy

Chiara Cimino Christian Krause

November 16, 2024

Chapter 1

Leroy Chapter I

1.1 F star

Definition 1 (Frame)**.** (Already in Mathlib)A Frame can be viewed as a Category. There exists a morphism between A and B iff $A \leq B$.

Definition 2 (Top -> Frame)**.** (Brauchen wir das überhaupt?) There exists a contravariant Functor from a topological Space to the corresponding Frame Category with open Sets as objects. $f : X \to O(X)$

Definition 3 (f^* and f_*)**.** For every continuous Function $f : X \to Y$ between topological Spaces, there exists a pair of functors (f^*, f_*).

$$f* = f^{-1} : O(Y) \to O(X)$$
$$f_* : O(X) \to O(Y) := A \mapsto \bigcup_{f^*(v) \leq A} v$$

Lemma 4 (f^* commutes)**.**
f^* commutes with finite meets and arbitrary joins. This is the same as saying that the Frame Category of open Sets has all small coproducts and all finite Limits. nlab

Lemma 5 (Homsets)**.** *(Already in Mathlib)*

$$Hom_{O(Y)}(f * (V), A) = Hom_{O(x)}(v, f_*(A))$$

Lemma 6 ($f^* \dashv f_*$)**.** *f^* is the right adjoint to f_**

Proof. □

Lemma 7 (triangle)**.** *(Mclane p. 485)*
The triangular identities reduce to the following equalities:

$$f^* f_* f^* = f^* \quad \textit{and} \quad f_* f^* f_* = f_*$$

Proof.
This follows from the triangular identities of the adjunction. □

1.2 Embedding

Lemma 8 (Embedding)**.** *(Leroy Lemme 1) The following arguments are equivalent:*

1. f^* *is surjective*
2. f_* *is injective*
3. $f^* f_* = 1_{O(X)})$

Proof. This follows from the triangular identities. $\square$

Definition 9 (Embedding)**.** An embedding is a morphism that satisfies the conditions of lemma 8

1.3 Subspaces

Definition 10 (Nucleus)**.** A nucleus is a map $e : O(E) \to O(E)$ with the following three properties:

1. e is idempotent
2. $U \leq eU$
3. $e(U \cap V) = e(U) \cap e(V)$

Lemma 11 (Nucleus)**.** *(Leroy Lemme 3) Let $e : O(E) \to O(E)$ be a nucleus. Then there is a space X and a morphism $f : X \to E$ such that $e = f_* f^*$. (The same holds for embeddings ??)*

Definition 12 (Subframe)**.** (Leroy CH 3) A subspace $Y \subset X$ is defined by a nucleus $e_Y : O(X) \to O(X)$, such that $O(Y) = Im(e_Y) = \{U \in O(X) | e_Y(U) = U\}$. The corresponding embedding (???) is $i_X : O(Y) \to O(X)$. $i_X^*(V) = e_X(V)$, $(i_X)_*(U) = U$

And every nucleus e on $O(X)$ defines a subspace Y of X by $O(Y) = Im(e)$

Definition 13 (Subframe Inclusion)**.** (Stimmt das?)(Leroy Ch 3) $X \subset Y$ if $e_Y \leq e_X$

Lemma 14 (factorisation)**.** *(Leroy Lemme 2) Let $i : X \to E$ be an embedding and $f : Y \to E$ be a morphism of spaces. To have f factor through i, it is necessary and sufficient that $i_* i^*(V) \leq f_* f^*(V) forall V \in O(E)$.*

Lemma 15 (Familiy of subspaces)**.** *(Leroy CH 4) Let X_i be a family of subspaces of E and e_i be the corresponding nuclei. For every $V \in O(E)$, let $e(V)$ be the onion of all $W \in O(E)$ which are contained in every $e_i(V)$. Then*

1. *e is the corresponding nucleus of a subspace X of E*
2. *a subspace Z of E contains x if and only if it contains all X_i x is thus called the union of X_i denoted by $\bigcup_i X_i$*

1.3.1 Direct Images

Definition 16 (Direct Images)**.** Let $f : E \to F$ be a morphism of spaces. The map $f_* f^* : O(F) \to O(F)$ is the nucleus of the subspace $Im(f)$ of F. By (lemma 2), $Im(F)$ is the smallest subspace of F through which f can be factored. For any subspace X of E, we define the direct image as

$$f(x) = Im(fi_x)$$

Where i_X is the inclusion of X into E.

Lemma 17 ((4) Direct Images Transitive)**.** *(Leroy Lemme 4) Given two morphisms $f : E \to F$ and $g : F \to G$ and a subspace X of E, we have*

$$(gf)(X) = g(f(X))$$

Lemma 18 ((5) Direct Images Families)**.** *(Leroy Lemme 5) For all morphisms $f : E \to F$ and a family (X_i) of subspaces of E, the following holds:*

$$f(\cup_i X_i) = \cup_i f(X_i)$$

1.3.2 Inverse Images

Definition 19 (Inverse Images)**.** We have a morphism of spaces $f : E \to F$ and a subspace Y of F. The inverse image $f^{-1}(Y)$ is the biggest subspace X of E such that $f(X) \subset Y$.
More generally for a morphism $h : A \to E$, the necessary and sufficient condition for h to factor through f^{-1} is that fh factors through Y.

$$Imh \subset f^{-1}(Y) \iff f(Imh) \subset Y \iff Im(fh) \subset Y$$

1.3.3 Open subspaces

Definition 20 (e_U)**.** TODO bessere benennung Let E be a space with $U, H \in O(E)$. We donote by e_U the largest $W \in O(E)$ such that $W \cap U \subset H$. We verify that e_U is the nucleus of a subspace, which we will temporarily denote by $[U]$.

Definition 21 (Open sublocal)**.** For any $U \in O(E)$, the sublocal $[U]$ is called an open sublocal of E. (+Senf: stimmt das mit dem üblichen überein???)

Lemma 22 ((6,7) Open subspaces)**.** *(Leroy Lemma 6,7)*

1. *For all subspaces X of E and any $U \in O(E)$:*

$$X \subset [U] \iff e_X(U) = 1_E$$

2. *For all $U, V \in O(E)$, we have:*

$$[U \cap V] = [U] \cap [V]$$

$$e_{U \cap V} = e_U e_V = e_V e_U$$

$$U \subset V \iff [U] \subset [V]$$

3. *For all families V_i of elements of $O(E)$, we have:*

$$\cup_i [V_i] = [\cup_i V_i]$$

4. *For all morphisms of spaces $f : E \to F$ and all $V \in O(E)$, we have:*

$$f^{-1}([V])] = [f^*(V)]$$

5. *Let X be a subspace of E and $U \in O(E)$. For all $V \in O(E)$, we have:*

$$V \subset e_X(U) \iff [V] \cap X \subset [U]$$

Definition 23 (Complement)**.** The complement of an open sublocal U of X is the sublocal $X \setminus U$. (Leroy p. 12) (+ Senf brauchen wir das allgemein??)

Lemma 24 ((1.8) Properties of Complements)**.** *For any any open sublocal V of E and any sublocal X of E, we have:*

$$V \cup X = E \iff E \setminus V subset X$$

$$V \cap X = \emptyset \iff X \subset E \setminus V$$

And thereby:

$$(E - U = E - V) \implies U = V$$

Lemma 25 ((1.9) Preimage of complements)**.** *For any morphism of spaces $g : A \to E$ and any open sublocal V of F, we have:*

$$g^{-1}(E - V) = A - g^{-1}(V)$$

Lemma 26 ((1.8bis) Properties of Complements Part 2)**.** *For any open sublocal V of E and any sublocal X of E, we have:*

$$V \cup (E - V) = E \iff V \subset X$$

$$V \cap (E - V) = \emptyset X \subset V$$

Lemma 27 ((1.10) Nucleus and Intersection)**.** *For any $U \in O(E)$, and sub local X of E we have:*

$$e_{U \cap X} = e_U e_X$$

And for a closed F

$$e_{X \cap F} = e_X e_F$$

Lemma 28 ((1.11) Distribution of Intersections over Unions)**.** *Let X, Y, L be three sub locals of E. If L is open or closed, we have:*

$$L \cap (X \cap Y) = (L \cap X) \cup (L \cap Y)$$

Definition 29 (Further Topology)**.**

1. $IntX$ is the largest open sublocal contained in X
2. $ExtX$ is the largest open sublocal contained in $E \setminus X$
3. $\bar{X}$ is the smallest closed sublocal containing X
4. $\partial X = \bar{X} \cap (E - IntX)$

Definition 30 (gamma)**.** $\gamma(E)$ is the minimal element of all dense sublocals of E.

Chapter 2

Leroy Chapter II

Definition 31 (Induced boolean algebra)**.** Define $At(U_1, \dots, U_n)$ as the collection of all finite nonempty intersections of opens U_i or their complements.
Define $b(U_1, \dots, U_n)$ as all unions of elements of $At(U_1, \dots, U_n)$
Define $b(X)$ as the union of all $b(U_1, \dots, U_n)$ for finite collections of opens U_i.

Lemma 32 ((2.1) Sublocals and decompositions)**.** *For any open U the natural morphism $p : U \sqcup (E \setminus U)$ induces a bijection of sublocals.*

Lemma 33 ((2.2) Induced morphism of boolean algebras)**.** *For all $H \in B(U_1, \dots, U_n)$ we have $f^{-1}(H) \in b(f^{-1}(U-1), \dots, f^{-1}(U_n))$ and*

$$H \mapsto f^{-1}(H)$$

Is a morphism of boolean algebras

Proposition 34 (Boolean algebra)**.** *(Leroy Proposition II.1)*

1. *$b(X)$ is the generated boolean algebra of the open and closed sublocals of X.*
2. *For all $H \in b(X)$, we have $f^{-1}(H) \in b(Y)$ and the map $H \to f^{-1}(H)$ is a homomorphism of boolean algebras $b(X) \to b(Y)$*
3. *For two sublocals A, B of X and any $H \in b(X)$, we have:*

$$H \cap (A \cup B) = (H \cap A) \cup (H \cap B)$$

Lemma 35 ($b(X)$ generates sublocals)**.** *Every sublocal X is an intersection of elements of $b(X)$.*

Lemma 36 (Union of Intersections)**.** *(Leroy Lemme 2.4) For any family B_i of sublocals of a local E and a sublocal A, we have:*

$$A \cup (\bigcap_i B_i) = \bigcap_i (A \cap B_i)$$

This implies if A_i and B_j are families of sublocals of X, we have:

$$(\bigcap_i A_i) \cup (\bigcap_j B_j) = \bigcap_{ij} (A_i \cup B_j)$$

Theorem 37 (Preimage commutes with unions)**.** *(Leroy resultat principal) For any morphism f of locals, we have:*

$$f^{-1}(A \cup B) = f^{-1}(A) \cup f^{-1}(B)$$

Chapter 3

Leroy Chapter III

Definition 38 (Measure on Locals)**.** A measure on a local X is a map $\mu : O(X) \to [0, \infty)$ such that:

1. $\mu(\emptyset) = 0$
2. $U \subset V \implies \mu(U) \leq \mu(V)$
3. $\mu(U \cup V) = \mu(U) + \mu(V) - \mu(V \cap V)$
4. For any increasingly filtered family V_i of open sublocals of X, we have:

$$\mu(\bigcup V_i) = \sup_i \mu(V_i)$$

(Leroy III.1.)

Definition 39 (Caratheodory)**.** For any measure on a local X, the caratheodory extension is:

$$\mu(A) = \inf\{\mu(U) | A \subset U \in O(X)\}$$

Lemma 40 (Proptery 0 (Commutes with sup))**.** *(Leroy lemme 3.1) The caratheodory extension of a measure on a local commutes with unions of increasing families. (Senf von noa: commutes with filtered colimits)*

Definition 41 (Regular Local)**.**

Definition 42 (Neighborhood)**.** A neighborhood of a sublocal A of X is an open sublocal V of X such that $A \leq V$.

Lemma 43 (Regularity of Sublocals)**.** *(Leroy lemme 3.2) In a regular local, any sublocal is regular, meaning that it is the intersection of all open neighborhoods.*

Lemma 44 (Property 1)**.** *(Leroy Lemme 3.3) For any open sublocal U of a local X, the caratheodory extension of a measure on X satisfies*

$$\mu(U) + \mu(X \setminus U) = \mu(X)$$

Definition 45 (Intersection)**.** The intersection of any Family A_i of sublocals of a local E is defined as .... (+ Senf pullback)

Proposition 46 (Sublocals structure)**.** *Obacht TODO The sublocals of a local E form a complete (distributive vlt.) lattice with the operations of intersection and complement.*

Lemma 47 (Property 2)**.** *(Leroy Lemm 3.4) For any open sublocal U and any sublocal A of a local E, the caratheodory extension of a measure on X satisfies*

$$\mu(A) = \mu(A \cap U) + \mu(A \cap (E \setminus U))$$

Lemma 48 (Property 3)**.** *(Leroy Lemm 3.5) For a increasing family V_α of open sublocals of E and any sublocal A, we have:*

$$\mu(A \cap (\bigcup V_\alpha)) = \sup_\alpha \mu(A \cap V_\alpha)$$

Lemma 49 (Commutes with inf opens)**.** *(Leroy Lemme 3.6) For any measure on a local X and a decreasing family V_i of open sublocals, the caratheodory extension fulfills: $\mu(\inf V_i) = \inf \mu(V_i)$.*

Lemma 50 (Caratheodory Extensions are monotonic)**.** *TODO uses inlcusion of sublocals The caratheodory extension is monotonic i.e.*

$$A \leq B \implies \mu(A) \leq \mu(B)$$

Proposition 51 (Elementary Properties of Caratheodory Extensions)**.** *(Leroy lemme 3.3, 3.4, Corollary 3.1, Lemme 3.5) For any measure on a local X, the caratheodory extension satisfies the following properties:*

1. *It is monotonic i.e.*
$$A \leq B \implies \mu(A) \leq \mu(B)$$
2. *Commutes with unions of increasing families*
3. $\mu(U) + \mu(X \setminus U) = \mu(X)$
4. $\mu(A) = \mu(A \cap U) + \mu(A \cap (E \setminus U))$
5. *For a increasing family V_α of open sublocals of E and any sublocal A, we have:*
$$\mu(A \cap (\bigcup V_\alpha)) = \sup_\alpha \mu(A \cap V_\alpha)$$
6. *For any measure on a local X and a decreasing family V_i of open sublocals, the caratheodory extension fulfills: $\mu(\inf V_i) = \inf \mu(V_i)$.*

In particular, for two open sublocals U and V of X and any sublocal A of X, we have

$$\mu(A \cap (U \cup V)) = \mu(A \cap U) + \mu(A \cap V) - \mu(A \cap U \cap V)$$

Proposition 52 (strictly additve)**.** *(Leroy theorem 3.3.1) For any measure on a local X, the caratheodory extension is strictly additive i.e. $\mu(A \cup B) = \mu(A) + \mu(B) - \mu(A \cap B)$*

Proposition 53 (reductive)**.** *(Proposition 3.3.1) For any measure on a local X, the caratheodory extension is reductive i.e. for all $A \leq X$ the set $\{A' \subset A, \mu(A') = \mu(A)\}$ has a minimal element*

Proposition 54 (Commutes with inf)**.** *(Leroy lemme 3.7 et principal) For any measure on a local X, the caratheodory extension is regular $\mu(\inf A_i) = \inf \mu(A_i)$. For decreasing families A_i*

Theorem 55 (Main Theorem (very important))**.** *For any measure on a local X, the caratheodory extension is*

1. *strictly additive i.e. $\mu(A \cup B) = \mu(A) + \mu(B) - \mu(A \cap B)$*
2. *commutes with inf $\mu(\inf A_i) = \inf \mu(A_i)$*
3. *reductive i.e. for all $A \leq X$ the set $\{A' \subset A, \mu(A') = \mu(A)\}$ has a minimal element*

Chapter 4

Leroy Chapter V

Lemma 56 (Regular Top to regular local)**.** *Any regular topological space induces a regular local.*

Lemma 57 (Opens)**.** *(Leroy V.1 Remarque 2) The Open subsets of any good enough topological space correspond precisely to the open sublocals of the corresponding local.*

Lemma 58 (Subset Sublocal)**.** *(leroy V.1 Remarque 3) Any subset X of a good enough topological space E induces a sublocal $[X]$ of the corresponding local. This is an order preserving embedding.*

Definition 59 (Good enough topological space)**.** blackbox to mathlib????)

Lemma 60 (Subset to sublocal Part 1)**.** *(Leroy Proposition 5.1.1)*
For two subspaces X and Y of E and an open subspaces U of E, we have:

1. $X \subset Y \implies [X] \subset [Y]$
2. $X \subset U \iff [X] \subset [U]$
3. *If E is a good enough topological space, then*

$$X \subset Y \iff [X] \subset [Y]$$

Lemma 61 (Subset to sublocal Part 2)**.** *(Leroy Proposition 5.1.2, 5.1.3) For an open subspace U of E and a subspace X of E, we have:*

$$[U \cap X] = [U] \cap [X]$$
$$F = E \setminus U$$
$$[F] = [E]$$
$$[U]$$
$$X \cap F] = [X] \cap [F]$$

Lemma 62 ((Prop 4) Unions of subspaces)**.** *(Leroy Proposition 5.1.4) For a family X_i of subspaces of E, we have:*

$$\bigcup_i [X_i] = [\bigcup_i X_i]$$

Lemma 63 (Part 3)**.** *For any subspaces X of E, we have:*

1. $$Ext[X] = [ExtX]$$

2. $$[\bar{X}] = [\bar{X}]$$

3. $$[IntX] \subset Int[X]$$

4. $$\partial[X] \subset [Fr(X)]$$

For a good enough topological space E, we have equality in 3 and 4.

Proposition 64 (Subset to sublocal preserves structure)**.** *For two subspaces X and Y of E and an open subspaces U of E, we have:*

1. $X \subset Y \implies [X] \subset [Y]$
2. $X \subset U \iff [X] \subset [U]$
3. *If E is a good enough topological space, then*
$$X \subset Y \iff [X] \subset [Y]$$
4. $$[U \cap X] = [U] \cap [X]$$
5. *...*

Theorem 65 (Measure top to loc)**.** *Any measure on a good enough topological space X induces a measure on the corresponding local. Furthermore, the classical caratheodory extension onto $\mathcal{P}(X)$ agrees with the restriction of the caratheodory extension of the induced measure on the local.*

Theorem 66 (Goal)**.** *One can interpret any classical borel measure as a measure on locals and their life is good :)*