

# A constant step stochastic Douglas Rachford algorithm

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## Notations

For every set  $T$ , we denote by  $\mathbb{R}^T$  the set of functions on  $T \rightarrow \mathbb{R}$ . If  $\mathcal{X}$  is a Euclidean space, we denote by  $\langle \cdot, \cdot \rangle$  the standard inner product on  $\mathcal{X}$ , and by  $\|\cdot\|$  the Euclidean norm.

We denote by  $\Gamma_0(\mathcal{X})$  the set of convex, proper and lower semicontinuous functions on  $\mathcal{X} \rightarrow (-\infty, +\infty]$ . For every  $h \in \Gamma_0(\mathcal{X})$ ,  $\gamma > 0$ , we introduce the *proximity operator*

$$\text{prox}_{\gamma, h}(x) = \arg \min_{w \in \mathcal{X}} h(w) + \frac{\|w - x\|^2}{2\gamma}$$

and the Moreau envelope

$$h_\gamma(x) = \min_{w \in \mathcal{X}} h(w) + \frac{\|w - x\|^2}{2\gamma}$$

for every  $x \in \mathcal{X}$ . We denote by  $\partial h(x)$  the subdifferential of  $h$  at the point  $x$ , by  $\partial h_0(x)$  the least norm element of  $\partial h(x)$ . Recall that  $h_\gamma$  is differentiable and  $\nabla h_\gamma(x) = \frac{1}{\gamma}(x - \text{prox}_{\gamma, h}(x))$ . If  $A$  is a set, the notation  $\iota_A$  stands for the indicator function of the set  $A$ , equal to zero on that set and to  $+\infty$  elsewhere. If  $R$  is a linear operator, we denote by  $R^*$  the adjoint operator. When  $D \subset E$ ,  $d(x, D)$  denote the distance from the point  $x \in E$  to  $D$  and if  $D$  is closed and convex,  $\Pi_D$  denote the projection onto  $D$ . The set of minimizers of  $h$  is the set of zeros of  $\partial h$  denoted  $Z(\partial h)$ .

## 1 Statement of the Problem

### 1.1 Douglas-Rachford algorithm

Consider the Problem

$$\min_{x \in \mathcal{X}} F(x) + G(x) \tag{1}$$

where  $F, G \in \Gamma_0(\mathcal{X})$ . The Douglas-Rachford algorithm writes

$$\begin{aligned} u^{(k+1)} &= \text{prox}_{\gamma, F}(x^{(k)}) \\ z^{(k+1)} &= \text{prox}_{\gamma, G}(2u^{(k+1)} - x^{(k)}) \\ x^{(k+1)} &= x^{(k)} + z^{(k+1)} - u^{(k+1)}. \end{aligned}$$

Under the standard qualification condition  $0 \in \text{ri}(\text{dom}(F) - \text{dom}(G))$  and assuming that the set of minimizers of problem (1) is non empty, the iterates  $\text{prox}_{\gamma, F}(x^{(k)})$  converge to a minimizer of problem (1) as  $k \rightarrow \infty$ .

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## 1.2 Adaptive Scenario

Let  $\xi$  be a random variable defined on some probability space  $(\Omega, \mathcal{F}, \mathbb{P})$  into an arbitrary measurable space  $(\Xi, \mathcal{G})$  with distribution  $\mu$ . We say that a mapping  $f : \mathcal{X} \times \Xi \rightarrow (-\infty, +\infty]$  is a normal convex integrand if  $f(\cdot, s) \in \Gamma_0(\mathcal{X})$  for every  $s \in \Xi$  and if  $f(x, \cdot)$  is measurable for every  $x \in \mathcal{X}$ . In this case, the expectation  $\mathbb{E}(f(x, \xi))$ .

blablabla

From now on, assume that the mapping  $F$  and  $G$  are of the form

$$\begin{aligned} F(x) &= \mathbb{E}(f(x, \xi)) \\ G(x) &= \mathbb{E}(g(x, \xi)) , \end{aligned}$$

where  $f, g$  are normal convex integrands. Denote by  $(\xi^{(k)} : k \in \mathbb{N})$  a sequence of iid copies of the r.v.  $\xi$ . In the sequel, we use the notation  $f^{(k)} := f(\cdot, \xi^{(k)})$  and  $g^{(k)} := g(\cdot, \xi^{(k)})$ . The adaptive Douglas-Rachford algorithm is given by

$$\begin{aligned} u^{k+1} &= \text{prox}_{\gamma, f^{(k+1)}}(x^{(k)}) \\ z^{k+1} &= \text{prox}_{\gamma, g^{(k+1)}}(2u^{k+1} - x^{(k)}) \\ x^{k+1} &= x^{(k)} + z^{(k+1)} - u^{(k+1)} . \end{aligned}$$

We denote by  $D(s)$  the domain of  $g(\cdot, s)$ , define the set  $\mathcal{D}$  by  $x \in \mathcal{D} \iff x \in D(\xi)$  a.s. and denote  $\mathbf{d}(x) = d(x, \mathcal{D})$ . We also denote  $F^\gamma(x) = \int f_\gamma(x, s) \mu(ds)$  and  $G^\gamma(x) = \int g_\gamma(x, s) \mu(ds)$ .

## 2 Theorem

- H1 There exists  $x_\star \in Z(\partial G + \nabla F)$  admitting a  $\mathcal{L}^2(\mu)$  representation  $(\varphi, \psi)$  i.e.  $\exists \varphi, \psi \in \mathcal{L}^2(\mu)$ , such that  $\varphi(\xi) \in \partial G(x_\star, \xi)$  a.s,  $\psi(\xi) = \nabla f(\xi, x_\star)$  a.s and  $\mathbb{E}(\varphi(\xi) + \psi(\xi)) = 0$ .
- H2 There exists  $L > 0$  s.t.  $\nabla f(\xi, \cdot)$  is a.s  $L$ -Lipschitz continuous.
- H3 The function  $F + G$  satisfies one of the following properties:
  - (a)  $F + G$  is coercive.
  - (b)  $F + G$  is supercoercive.
- H4 For every compact set  $\mathcal{K} \subset E$ , there exists  $\varepsilon > 0$  such that

$$\sup_{x \in \mathcal{K} \cap \mathcal{D}} \int \|\partial g_0(s, x)\|^{1+\varepsilon} \mu(ds) < \infty ,$$

- H5 There exists a closed ball in  $E$  such that  $\|\nabla f(s, x)\| \leq M(s)$  for all  $x$  in this ball, where  $M(s)$  is  $\mu$ -integrable. Moreover, for every compact set  $\mathcal{K} \subset E$ , there exists  $\varepsilon > 0$  such that

$$\sup_{x \in \mathcal{K}} \int \|\nabla f(s, x)\|^{1+\varepsilon} \mu(ds) < \infty .$$

- H6 For all  $\gamma \in (0, \gamma_0]$  and all  $x \in E$ ,

$$\int \left( \|\nabla f_\gamma(s, x)\| + \frac{1}{\gamma} \|\text{prox}_{\gamma g(s, \cdot)}(x) - \Pi_{\text{cl}(D(s))}(x)\| \right) \mu(ds) \leq C(1 + |F^\gamma(x) + G^\gamma(x)|) .$$

- H7  $\forall x \in E, \int d(x, D(s))^2 \mu(ds) \geq C \mathbf{d}(x)^2$ .

- H8 For every compact set  $\mathcal{K} \subset E$ , there exists  $\varepsilon > 0$  such that

$$\sup_{\gamma \in (0, \gamma_0], x \in \mathcal{K}} \frac{1}{\gamma^{1+\varepsilon}} \int \|\text{prox}_{\gamma g(s, \cdot)}(x) - \Pi_{\text{cl}(D(s))}(x)\|^{1+\varepsilon} \mu(ds) < \infty .$$

**Theorem 2.1.** Let Hypotheses H1–H8 hold true. Then, for each probability measure  $\nu$  having a finite second moment, for any  $\varepsilon > 0$ ,

$$\limsup_{n \rightarrow \infty} \frac{1}{n+1} \sum_{k=0}^n \mathbb{P}^{\nu, \gamma} (d(x_k, \arg \min(F+G)) > \varepsilon) \xrightarrow{\gamma \rightarrow 0} 0.$$

Moreover, if Hypothesis H3–(b) is satisfied, then

$$\begin{aligned} \limsup_{n \rightarrow \infty} \mathbb{P}^{\nu, \gamma} (d(\bar{x}_n, \arg \min(F+G)) \geq \varepsilon) &\xrightarrow{\gamma \rightarrow 0} 0, \text{ and} \\ \limsup_{n \rightarrow \infty} d(\mathbb{E}^{\nu, \gamma}(\bar{x}_n), \arg \min(F+G)) &\xrightarrow{\gamma \rightarrow 0} 0. \end{aligned}$$

### 3 Proof of Theorem 2.1

In this section, we study the iterations given by the adaptive Douglas Rachford algorithm. Let  $\gamma_0 > 0$ ,  $a \in E$  and  $(\xi_n^\gamma)_{n \in \mathbb{N}, \gamma \in (0, \gamma_0)}$  be an i.i.d sequence of random variables from  $(\Omega, \mathcal{F}, \mathbb{P})$  to  $(\Xi, \mathcal{G})$  with distribution  $\mu$ . The adaptive Douglas Rachford algorithm with step size  $\gamma > 0$  writes  $x_0^{\gamma, a} = a$  and for all  $n \in \mathbb{N}$ ,

$$x_{n+1}^{\gamma, a} = x_n^{\gamma, a} - \gamma \nabla f_\gamma(x_n^{\gamma, a}, \xi_{n+1}^\gamma) - \gamma \nabla g_\gamma(x_n^{\gamma, a} - 2\gamma \nabla f_\gamma(x_n^{\gamma, a}, \xi_{n+1}^\gamma), \xi_{n+1}^\gamma). \quad (2)$$

Define

$$h_\gamma(x, s) := -\nabla f_\gamma(x, s) - \nabla g_\gamma(x - 2\gamma \nabla f_\gamma(x, s), s).$$

The algorithm (2) can be rewritten as

$$x_{n+1}^{\gamma, a} = x_n^{\gamma, a} + \gamma h_\gamma(x_n^{\gamma, a}, \xi_{n+1}^\gamma). \quad (3)$$

In Sec. 3.1, we show that the linearly interpolated process constructed from the sequence  $(x_n)$  converges narrowly as  $\gamma \rightarrow 0$  to a DI solution in the topology of uniform convergence on compact sets. The main result of this section is Th. 3.1, which has its own interest. To prove this theorem, we establish the tightness of the linearly interpolated process (Lem. 3.2), then we show that the limit points coincide with the DI solution (Lem. 3.3–3.5). In Sec. 3.2, we start by establishing the inequality (??), which is shown in Lem. 3.6 with  $Q(x) = \Psi(x)$ . Using the tightness of  $\mathcal{I}(\mathcal{P})$  in conjunction with Th. 3.1, Lem 3.9 shows that the cluster points of  $\mathcal{I}(\mathcal{P})$  are elements of  $\mathcal{I}(\Phi)$ . In the different domains case, this lemma requires that the invariant measures of  $P_\gamma$  put most of their weights in a thickening of the domain  $\mathcal{D}$  of order  $\gamma$ . This fact is established by Lem. 3.8.

#### 3.1 Weak APT

For every  $\gamma > 0$ , we introduce the linearly interpolated process  $\mathbf{X}_\gamma : (E^\mathbb{N}, \mathcal{B}(E)^{\otimes \mathbb{N}}) \rightarrow (C(\mathbb{R}_+, E), \mathcal{B}(C(\mathbb{R}_+, E)))$ , defined for every  $x = (x_n : n \in \mathbb{N})$  in  $E^\mathbb{N}$  as

$$\mathbf{X}_\gamma(x) : t \mapsto x_{\lfloor \frac{t}{\gamma} \rfloor} + (t/\gamma - \lfloor t/\gamma \rfloor)(x_{\lfloor \frac{t}{\gamma} \rfloor + 1} - x_{\lfloor \frac{t}{\gamma} \rfloor}).$$

This map will be referred to as the linearly interpolated process. When  $x = (x_n)$  is the process with the probability measure  $\mathbb{P}^{\nu, \gamma}$  defined above, the distribution of the r.v.  $\mathbf{X}_\gamma$  is  $\mathbb{P}^{\nu, \gamma} \mathbf{X}_\gamma^{-1}$ .

The set  $C(\mathbb{R}_+, E)$  of continuous functions from  $\mathbb{R}_+$  to  $E$  is equipped with the topology of uniform convergence on the compact intervals, who is known to be compatible with the distance  $d$  defined as

$$d(x, y) := \sum_{n \in \mathbb{N}^*} 2^{-n} \left( 1 \wedge \sup_{t \in [0, n]} \|x(t) - y(t)\| \right).$$

If  $S$  is a subset of  $E$  and  $\varepsilon > 0$ , we denote by  $S_\varepsilon := \{a \in E : d(a, S) < \varepsilon\}$  the  $\varepsilon$ -neighborhood of  $S$ . The aim of the beginning section is to establish the following result:

**Theorem 3.1.** Let Assumptions H4, H5, H7 and H8 hold true. Then, for every  $\eta > 0$ , for every compact set  $\mathcal{K} \subset E$  s.t.  $\mathcal{K} \cap \mathcal{D} \neq \emptyset$ ,

$$\forall M \geq 0, \sup_{a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}} \mathbb{P}^{a, \gamma} (d(\mathbf{X}_\gamma, \Phi(\Pi_{\text{cl}(\mathcal{D})}(a), \cdot)) > \eta) \xrightarrow{\gamma \rightarrow 0} 0. \quad (4)$$

Choose a compact set  $\mathcal{K} \subset E$  s.t.  $\mathcal{K} \cap \text{cl}(\mathcal{D}) \neq \emptyset$ . Choose  $R > 0$  s.t.  $\mathcal{K}$  is contained in the ball of radius  $R$ . For every  $x = (x_n : n \in \mathbb{N})$  in  $E^\mathbb{N}$ , define  $\tau_R(x) := \inf\{n \in \mathbb{N} : x_n > R\}$  and introduce the measurable mapping  $C_R : E^\mathbb{N} \rightarrow E^\mathbb{N}$ , given by

$$C_R(x) : n \mapsto x_n \mathbb{1}_{n < \tau_R(x)} + x_{\tau_R(x)} \mathbb{1}_{n \geq \tau_R(x)}.$$

Consider the image measure  $\bar{\mathbb{P}}^{a, \gamma} := \mathbb{P}^{a, \gamma} C_R^{-1}$ , which corresponds to the law of the *truncated* process  $C_R(x)$ . The crux of the proof consists in showing that for every  $\eta > 0$  and every  $M > 0$ ,

$$\sup_{a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}} \bar{\mathbb{P}}^{a, \gamma} (d(\mathbf{X}_\gamma, \Phi(\Pi_{\text{cl}(\mathcal{D})}(a), \cdot)) > \eta) \xrightarrow{\gamma \rightarrow 0} 0. \quad (5)$$

Eq. (5) is the counterpart of [13, Lemma 4.3]. Once it has been proven, the conclusion follows verbatim from [13, Section 4, End of the proof]. Our aim is thus to establish Eq. (5). The proof follows the same steps as the proof of [13, Lemma 4.3] up to some confined changes. Here, the steps of the proof which do not need any modification are recalled rather briefly (we refer the reader to [13] for the details). On the other hand, the parts which require an adaptation are explicitly stated as lemmas, whose detailed proofs are provided at the end of this section.

Define  $h_{\gamma, R}(s, a) := h_\gamma(s, a) \mathbb{1}_{\|a\| \leq R}$ . First, we recall the following decomposition, established in [13]:

$$\mathbf{X}_\gamma = \Pi_0 + \mathbf{G}_{\gamma, R} \circ \mathbf{X}_\gamma + \mathbf{X}_\gamma \circ M_{\gamma, R},$$

$\bar{\mathbb{P}}^{a, \gamma}$  almost surely, where  $\Pi_0 : E^\mathbb{N} \rightarrow C(\mathbb{R}_+, E)$ ,  $\mathbf{G}_{\gamma, R} : C(\mathbb{R}_+, E) \rightarrow C(\mathbb{R}_+, E)$  and  $\Delta_{\gamma, R} : E^\mathbb{N} \rightarrow E^\mathbb{N}$  are the mappings respectively defined by

$$\begin{aligned} \Pi_0(x) : t &\mapsto x_0 \\ M_{\gamma, R}(x) : n &\mapsto (x_n - x_0) - \gamma \sum_{k=0}^{n-1} \int h_{\gamma, R}(s, x_k) \mu(ds) \\ \mathbf{G}_{\gamma, R}(\mathbf{x}) : t &\mapsto \int_0^t \int h_{\gamma, R}(s, \mathbf{x}(\gamma \lfloor u/\gamma \rfloor)) \mu(ds) du, \end{aligned}$$

for every  $x = (x_n : n \in \mathbb{N})$  and every  $\mathbf{x} \in C(\mathbb{R}_+, E)$ .

**Lemma 3.2.** For all  $\gamma \in (0, \gamma_0]$  and all  $x \in E^\mathbb{N}$ , define  $Z_{n+1}^\gamma(x) := \gamma^{-1}(x_{n+1} - x_n)$ . There exists  $\varepsilon > 0$  such that:

$$\sup_{n \in \mathbb{N}, a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}, \gamma \in (0, \gamma_0]} \bar{\mathbb{E}}^{a, \gamma} \left( \left( \|Z_n^\gamma\| + \frac{\mathbf{d}(x_n)}{\gamma} \mathbb{1}_{\|x_n\| \leq R} \right)^{1+\varepsilon} \right) < +\infty \quad (6)$$

*Proof.* Let  $\varepsilon$  be the smallest of the three constants (also named  $\varepsilon$ ) in Assumptions H4, H5 and H8 respectively where  $\mathcal{K} = B_R$ . For every  $a, \gamma$ , the following holds for  $\bar{\mathbb{P}}^{a, \gamma}$ -almost all  $x = (x_n : n \in \mathbb{N})$ :

$$\begin{aligned} \mathbf{d}(x_{n+1}) \mathbb{1}_{\|x_{n+1}\| \leq R} &= \mathbf{d}(x_{n+1}) \mathbb{1}_{\|x_{n+1}\| \leq R} (\mathbb{1}_{\|x_n\| \leq R} + \mathbb{1}_{\|x_n\| > R}) = \mathbf{d}(x_{n+1}) \mathbb{1}_{\|x_{n+1}\| \leq R} \mathbb{1}_{\|x_n\| \leq R} \\ &\leq \mathbf{d}(x_{n+1}) \mathbb{1}_{\|x_n\| \leq R} \\ &= \|x_{n+1} - \Pi_{\mathcal{D}}(x_{n+1})\| \mathbb{1}_{\|x_n\| \leq R} \\ &\leq \|x_{n+1} - \Pi_{\mathcal{D}}(x_n)\| \mathbb{1}_{\|x_n\| \leq R}. \end{aligned}$$

Using the notation  $\bar{\mathbb{E}}_n^{a, \gamma} = \bar{\mathbb{E}}^{a, \gamma}(\cdot | x_0, \dots, x_n)$ , we thus obtain:

$$\bar{\mathbb{E}}_n^{a, \gamma} (\mathbf{d}(x_{n+1})^{1+\varepsilon} \mathbb{1}_{\|x_{n+1}\| \leq R}) \leq \int \|x_n + \gamma h_\gamma(s, x_n) - \Pi_{\mathcal{D}}(x_n)\|^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s).$$

By the convexity of  $\|\cdot\|^{1+\varepsilon}$ , for all  $\alpha \in (0, 1)$ ,

$$\|x + y\|^{1+\varepsilon} = \frac{1}{\alpha^{1+\varepsilon}} \left\| \alpha x + (1 - \alpha) \frac{\alpha}{1 - \alpha} y \right\|^{1+\varepsilon} \leq \alpha^{-\varepsilon} \|x\|^{1+\varepsilon} + (1 - \alpha)^{-\varepsilon} \|y\|^{1+\varepsilon}.$$

Therefore, by setting  $\delta_\gamma(s, a) := \|a + \gamma h_\gamma(s, a) - \Pi_{D(s)}(a)\|$ ,

$$\begin{aligned} \bar{\mathbb{E}}_n^{a, \gamma}(\mathbf{d}(x_{n+1})^{1+\varepsilon} \mathbb{1}_{\|x_{n+1}\| \leq R}) &\leq \alpha^{-\varepsilon} \int \delta_\gamma(s, x_n)^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s) \\ &\quad + (1 - \alpha)^{-\varepsilon} \int \|\Pi_{D(s)}(x_n) - \Pi_{\mathcal{D}}(x_n)\|^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s). \end{aligned}$$

Note that for every  $s \in \Xi$ ,  $a \in E$ ,

$$\delta_\gamma(s, a) = \text{prox}_{\gamma g(s, \cdot)}(a - 2\gamma \nabla f_\gamma(s, a)) + \gamma \nabla f_\gamma(s, a) - \Pi_{D(s)}(a) + \text{prox}_{\gamma g(s, \cdot)}(a) - \text{prox}_{\gamma g(s, \cdot)}(a)$$

Hence,

$$\|\delta_\gamma(s, a)\| \leq 3\gamma \|\nabla f_\gamma(s, a)\| + \|\text{prox}_{\gamma g(s, \cdot)}(a) - \Pi_{D(s)}(a)\|$$

And, by Assumptions H4 and H5, there exists a deterministic constant  $C > 0$  s.t.

$$\sup_n \int \delta_\gamma(s, x_n)^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s) \leq C\gamma^{1+\varepsilon}.$$

Moreover, since  $\Pi_{\text{cl}(D(s))}$  is a firmly non expansive operator [6, Chap. 4], it holds that for all  $u \in \text{cl}(\mathcal{D})$ , and for  $\mu$ -almost all  $s$ ,

$$\|\Pi_{\text{cl}(D(s))}(x_n) - u\|^2 \leq \|x_n - u\|^2 - \|\Pi_{\text{cl}(D(s))}(x_n) - x_n\|^2.$$

Taking  $u = \Pi_{\text{cl}(\mathcal{D})}(x_n)$ , we obtain that

$$\|\Pi_{\text{cl}(D(s))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\|^2 \leq \mathbf{d}(x_n)^2 - d(x_n, D(s))^2. \quad (7)$$

Making use of Assumption H7, and assuming without loss of generality that  $\varepsilon \leq 1$ , we obtain

$$\begin{aligned} \int \|\Pi_{\text{cl}(D(s))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\|^{1+\varepsilon} d\mu(s) &\leq \left( \int \|\Pi_{\text{cl}(D(s))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\|^2 d\mu(s) \right)^{(1+\varepsilon)/2} \\ &\leq \alpha' \mathbf{d}(x_n)^{1+\varepsilon}, \end{aligned}$$

for some  $\alpha' \in [0, 1)$ . Choosing  $\alpha$  close enough to zero, we obtain that there exists  $\rho \in [0, 1)$  such that

$$\bar{\mathbb{E}}_n^{a, \gamma} \left( \frac{\mathbf{d}(x_{n+1})^{1+\varepsilon}}{\gamma^{1+\varepsilon}} \mathbb{1}_{\|x_{n+1}\| \leq R} \right) \leq \rho \frac{\mathbf{d}(x_n)^{1+\varepsilon}}{\gamma^{1+\varepsilon}} \mathbb{1}_{\|x_n\| \leq R} + C.$$

Taking the expectation at both sides, iterating, and using the fact that  $\mathbf{d}(x_0) = \mathbf{d}(a) < M\gamma$ , we obtain that

$$\sup_{n \in \mathbb{N}, a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}, \gamma \in (0, \gamma_0]} \bar{\mathbb{E}}^{a, \gamma} \left( \left( \frac{\mathbf{d}(x_n)}{\gamma} \right)^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} \right) < +\infty. \quad (8)$$

Since  $\nabla g_\gamma(s, \cdot)$  is  $\gamma^{-1}$ -Lipschitz continuous,  $\|h_\gamma(s, x)\| \leq \|\nabla g_\gamma(s, x)\| + 3\|\nabla f_\gamma(s, x)\|$ . Moreover, choosing measurably  $\tilde{x} \in \mathcal{D}$  in such a way that  $\|x - \tilde{x}\| \leq 2\mathbf{d}(x)$ , we obtain  $\|\nabla g_\gamma(s, x)\| \leq \|\partial g_0(s, \tilde{x})\| + 2\frac{\mathbf{d}(x)}{\gamma}$ . Therefore, there exists  $R'$  depending only on  $R$  and  $\mathcal{D}$  s.t.

$$\|\nabla g_\gamma(s, x)\| \mathbb{1}_{\|x\| \leq R} \leq \|\partial g_0(s, \tilde{x})\| \mathbb{1}_{\|\tilde{x}\| \leq R'} + 2\frac{\mathbf{d}(x)}{\gamma} \mathbb{1}_{\|x\| \leq R}.$$

In the following,  $C$  is a positive constant that can change from a line to another. Choosing  $\varepsilon > 0$  enough small and using Assumption H4, H5 and Eq. (8), we have

$$\begin{aligned}
\bar{\mathbb{E}}_n^{a,\gamma}(\|Z_{n+1}^\gamma\|^{1+\varepsilon}) &= \int \|h_\gamma(s, x_n)\|^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s) \\
&\leq \int (\|\nabla g_\gamma(s, x_n)\| + 3\|\nabla f_\gamma(s, x_n)\|)^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s) \\
&\leq C \int \|\nabla g_\gamma(s, x_n)\|^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} + \|\nabla f_\gamma(s, x_n)\|^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s) \\
&\leq C \int \|\partial g_0(s, \tilde{x}_n)\|^{1+\varepsilon} \mathbb{1}_{\|\tilde{x}_n\| \leq R'} d\mu(s) + C \int \|\nabla f_\gamma(s, x_n)\|^{1+\varepsilon} \mathbb{1}_{\|x_n\| \leq R} d\mu(s) \\
&\quad + C \frac{\mathbf{d}(x_n)^{1+\varepsilon}}{\gamma} \mathbb{1}_{\|x_n\| \leq R} \\
&\leq C + C \frac{\mathbf{d}(x_n)^{1+\varepsilon}}{\gamma} \mathbb{1}_{\|x_n\| \leq R}.
\end{aligned} \tag{9}$$

Taking expectations, the bound (6) is established.  $\square$

Using [13, Lemma 4.2], the uniform integrability condition (6) implies<sup>1</sup> that  $\{\bar{\mathbb{P}}^{a,\gamma} \mathbf{X}_\gamma^{-1} : a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}, \gamma \in (0, \gamma_0]\}$  is tight, and for any  $T > 0$ ,

$$\sup_{a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}} \bar{\mathbb{P}}^{a,\gamma}(\|\mathbf{X}_\gamma \circ M_{\gamma,R}\|_{\infty,T} > \varepsilon) \xrightarrow{\gamma \rightarrow 0} 0, \tag{10}$$

where the notation  $\|\mathbf{x}\|_{\infty,T}$  stands for the uniform norm of  $\mathbf{x}$  on  $[0, T]$ .

**Lemma 3.3.** For an arbitrary sequence  $(a_n, \gamma_n)$  such that  $a_n \in \mathcal{K} \cap \mathcal{D}_{\gamma_n M}$  and  $\gamma_n \rightarrow 0$ , there exists a subsequence (still denoted as  $(a_n, \gamma_n)$ ) such that  $(a_n, \gamma_n) \rightarrow (a^*, 0)$  for some  $a^* \in \mathcal{K} \cap \text{cl}(\mathcal{D})$ , and there exists r.v.  $\mathbf{z}$  and  $(\mathbf{x}_n : n \in \mathbb{N})$  defined on some probability space  $(\Omega', \mathcal{F}', \mathbb{P}')$  into  $C(\mathbb{R}_+, E)$  s.t.  $\mathbf{x}_n$  has the distribution  $\bar{\mathbb{P}}^{a_n, \gamma_n} \mathbf{X}_{\gamma_n}^{-1}$  and  $\mathbf{x}_n(\omega) \rightarrow \mathbf{z}(\omega)$  for all  $\omega \in \Omega'$ . Moreover, defining

$$u_n(t) := \mathbf{x}_n(\gamma_n \lfloor t/\gamma_n \rfloor),$$

the sequence  $(a_n, \gamma_n)$  and  $(\mathbf{x}_n)$  can be chosen in such a way that the following holds  $\mathbb{P}'$ -a.e.

$$\sup_n \int_0^T \left( \frac{\mathbf{d}(u_n(t))}{\gamma_n} \mathbb{1}_{\|u_n(t)\| \leq R} \right)^{1+\frac{\varepsilon}{2}} dt < +\infty \quad (\forall T > 0), \tag{11}$$

where  $\varepsilon > 0$  is the constant introduced in Lem. 3.2.

*Proof.* See [?].  $\square$

Define

$$v_n(s, t) := -\nabla f_{\gamma_n}(s, u_n(t)) \mathbb{1}_{\|u_n(t)\| \leq R}.$$

and

$$w_n(s, t) := -\nabla g_{\gamma_n}(s, u_n(t) - 2\gamma \nabla f_{\gamma_n}(s, u_n(t))) \mathbb{1}_{\|u_n(t)\| \leq R}.$$

Thanks to the convergence (10), the following holds  $\mathbb{P}'$ -a.e.:

$$\mathbf{z}(t) = \mathbf{z}(0) + \lim_{n \rightarrow \infty} \int_0^t \int_{\Xi} v_n(s, u) + w_n(s, u) \mu(ds) du \quad (\forall t \geq 0). \tag{12}$$

---

<sup>1</sup>Lemma 4.2 of [13] was actually shown with condition  $[a \in \mathcal{K}]$  instead of  $[a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}]$ , but the proof can be easily adapted to the latter case.

We now select an  $\omega \in \Omega'$  s.t. the events (11) and (12) are all realized, and omit the dependence in  $\omega$  in the sequel. Otherwise stated,  $u_n$ ,  $v_n$  and  $w_n$  are handled from now on as deterministic functions, and no longer as random variables. The aim of the next lemmas is to analyze the integrand  $v_n(s, u) + w_n(s, u)$ . Consider some  $T > 0$  and let  $\lambda_T$  represent the Lebesgue measure on the interval  $[0, T]$ . To simplify notations, we set  $\mathcal{L}_E^{1+\varepsilon} := \mathcal{L}^{1+\varepsilon}(\Xi \times [0, T], \mathcal{G} \otimes \mathcal{B}([0, T]), \mu \otimes \lambda_T; E)$ .

**Lemma 3.4.** The sequences  $(v_n : n \in \mathbb{N})$ ,  $(w_n : n \in \mathbb{N})$  form bounded subsets of  $\mathcal{L}_E^{1+\varepsilon/2}$ .

*Proof.* By the same derivations as those leading to Eq. (9), there exists  $C > 0$  such that

$$\int (\|v_n(s, t)\|^{1+\varepsilon/2} + \|w_n(s, t)\|^{1+\varepsilon/2}) d\mu(s) \leq C + C \frac{d(u_n(t))^{1+\varepsilon/2}}{\gamma^{1+\varepsilon/2}} \mathbb{1}_{\|u_n(t)\| \leq R}.$$

The proof is concluded by applying Lem. 3.3. □

The sequence of mappings  $((s, t) \mapsto (v_n(s, t), w_n(s, t)))$  is bounded in  $\mathcal{L}_{E^2}^{1+\varepsilon/2}$  and therefore admits a weak cluster point in that space. We denote by  $(v, w)$  such a cluster point, where  $v : \Xi \times [0, T] \rightarrow E$  and  $w : \Xi \times [0, T] \rightarrow E$ . Let  $H_R(s, a) := \nabla f(s, a) + \partial g(s, a)$  if  $\|a\| < R$ , and  $H_R(s, a) := E$  otherwise.

Denote the corresponding selection integral as  $H_R(a) = \int H_R(s, a) \mu(ds)$ .

à définir plus haut

**Lemma 3.5.** For every  $(s, t)$   $\mu \otimes \lambda_T$ -a.e.,  $(z(t), (v + w)(s, t)) \in \text{gr}(H_R(s, \cdot))$ .

*Proof.* To simplify notations, we now omit the dependence in  $(s, t)$  in the sequel and write  $u_n := u_n(t)$ ,  $v_n := v_n(s, t)$ ,  $w_n := w_n(s, t)$ ,  $h_\gamma := h_\gamma(s, \cdot)$ ,  $\partial g := \partial g(s, \cdot)$ ,  $\nabla f := \nabla f(s, \cdot)$ ,  $\gamma := \gamma_n$ ,  $\text{prox}_{\gamma f} := \text{prox}_{\gamma f(s, \cdot)}$ ,  $\nabla f_\gamma := \nabla f_\gamma(s, \cdot)$ ,  $z := z(t)$ . Moreover, we write  $\widetilde{\text{prox}}_{\gamma g}(x) := \text{prox}_{\gamma g(s, \cdot)}(x - 2\gamma \nabla f_\gamma(s, x))$  and  $\widetilde{\nabla} g_\gamma := \nabla g_\gamma(s, x - 2\gamma \nabla f_\gamma(s, x))$ , for all  $x \in E$ .

There exists a subsequence of  $(\gamma_n)$  that is decreasing and such that  $d_n := \sup_{t \in [0, T]} \|u_n(t) - z(t)\|$  is decreasing to zero. We still denote by  $(\gamma_n)$  such a subsequence. The sequence  $((v_n, w_n, \|v_n\|, \|w_n\|))_n$  converges weakly to  $(v, w, \tilde{v}, \tilde{w})$  in  $\mathcal{L}_{E^2 \times \mathbb{R}^2}^{1+\varepsilon/2}$  along some subsequence (*n.b.*: compactness and sequential compactness are the same notions in the weak topology of  $\mathcal{L}_{E \times \mathbb{R}}^{1+\varepsilon/2}$ ). We still denote by  $((v_n, w_n, \|v_n\|, \|w_n\|))_n$  this subsequence. By Mazur's theorem, there exists a function  $J : \mathbb{N} \rightarrow \mathbb{N}$  and a sequence of sets of weights  $\{\alpha_{k,n} : n \in \mathbb{N}, k = n \dots, J(n) : \alpha_{k,n} \geq 0, \sum_{k=n}^{J(n)} \alpha_{k,n} = 1\}$  such that the sequence of functions

$$(\bar{v}_n, \bar{w}_n, \tilde{v}_n, \tilde{w}_n) : (s, t) \mapsto \sum_{k=n}^{J(n)} \alpha_{k,n} (v_k(s, t), w_k(s, t), \|v_k(s, t)\|, \|w_k(s, t)\|)$$

converges strongly to  $(v, w, \tilde{v}, \tilde{w})$  in that space, as  $n \rightarrow \infty$ . Taking a further subsequence (which we still denote by  $(\bar{v}_n, \bar{w}_n, \tilde{v}_n, \tilde{w}_n)$ ) we obtain the  $\mu \otimes \lambda_T$ -almost everywhere convergence of  $(\bar{v}_n, \bar{w}_n, \tilde{v}_n, \tilde{w}_n)$  to  $(\bar{v}, \bar{w}, \tilde{v}, \tilde{w})$ . Consider a negligible set  $\mathcal{N} \in \mathcal{G} \otimes \mathcal{B}([0, T])$  such that for all  $(s, t) \notin \mathcal{N}$ ,  $(\bar{v}_n, \bar{w}_n, \tilde{v}_n, \tilde{w}_n) \rightarrow (v, w, \tilde{v}, \tilde{w})$  and  $\tilde{v}, \tilde{w}$  are finite.

If  $\|z(t)\| \geq R$ , obviously  $(z(t), (v + w)(s, t)) \in \text{gr}(H_R(s, \cdot))$ . We just need to consider the case where  $\|z(t)\| < R$ . Besides, the condition  $(z(t), (v + w)(s, t)) \in \text{gr}(H_R(s, \cdot))$  is equivalent to:

$$(z(t), -(v + w)(s, t)) \in \text{gr}(\nabla f(s, \cdot) + \partial g(s, \cdot)). \quad (13)$$

To show Eq. (13), consider an arbitrary  $(p, q) \in \text{gr}(\nabla f(s, \cdot) + \partial g(s, \cdot))$ . There exists  $(q_f, q_g) \in E^2$  such that  $q = q_f + q_g$ ,  $(p, q_f) \in \text{gr}(\nabla f(s, \cdot))$  and  $(p, q_g) \in \text{gr}(\partial g(s, \cdot))$ .

Recall that  $-h_\gamma(x) = \nabla f_\gamma(x) + \nabla g_\gamma(x - 2\gamma \nabla f_\gamma(x))$ . We start by decomposing  $\langle x - p, -h_\gamma(x) - q \rangle$  for any  $x \in E$ . On the one hand,

$$\langle x + \gamma h_\gamma(x) - p, -h_\gamma(x) - q \rangle = -\gamma \langle h_\gamma(x), q \rangle - \gamma \|h_\gamma(x)\|^2 + \langle x - p, -h_\gamma(x) - q \rangle$$

On the other hand,

$$\begin{aligned}
& \langle x - \gamma \nabla f_\gamma(x) - \gamma \widetilde{\nabla} g_\gamma(x) - p, \nabla f_\gamma(x) + \widetilde{\nabla} g_\gamma(x) - (q_f + q_g) \rangle \\
&= \langle \text{prox}_{\gamma f}(x) - \gamma \widetilde{\nabla} g_\gamma(x) - p, \nabla f_\gamma(x) - q_f \rangle + \langle \widetilde{\text{prox}}_{\gamma g}(x) + \gamma \nabla f_\gamma(x) - p, \widetilde{\nabla} g_\gamma(x) - q_g \rangle \\
&= \langle \text{prox}_{\gamma f}(x) - p, \nabla f_\gamma(x) - q_f \rangle + \langle \widetilde{\text{prox}}_{\gamma g}(x) - p, \widetilde{\nabla} g_\gamma(x) - q_g \rangle \\
&\quad - \gamma \langle \widetilde{\nabla} g_\gamma(x), \nabla f_\gamma(x) - q_f \rangle + \gamma \langle \nabla f_\gamma(x), \widetilde{\nabla} g_\gamma(x) - q_g \rangle \\
&= \langle \text{prox}_{\gamma f}(x) - p, \nabla f_\gamma(x) - q_f \rangle + \langle \widetilde{\text{prox}}_{\gamma g}(x) - p, \widetilde{\nabla} g_\gamma(x) - q_g \rangle \\
&\quad + \gamma \langle \widetilde{\nabla} g_\gamma(x), q_f \rangle - \gamma \langle \nabla f_\gamma(x), q_g \rangle.
\end{aligned}$$

Using the monotonicity of  $\nabla f$  and  $\partial g$ , we finally have

$$\begin{aligned}
0 &\leq \langle x - p, -h_\gamma(x) - q \rangle \\
&\quad - \gamma \langle \widetilde{\nabla} g_\gamma(x), q_f \rangle + \gamma \langle \nabla f_\gamma(x), q_g \rangle - \gamma \langle h_\gamma(x), q \rangle.
\end{aligned} \tag{14}$$

As  $\|z\| < R$ , it holds that  $\|u_n\| < R$  for every  $n$  large enough. Thus,  $-v_n = \nabla f_{\gamma_n}(u_n)$  and  $-w_n = \nabla g_{\gamma_n}(u_n - 2\gamma_n \nabla f_{\gamma_n}(u_n))$ . Using (14) with  $u_n$  instead of  $x$  and  $\gamma_n$  instead of  $\gamma$ , we have

$$\begin{aligned}
0 &\leq \sum_{k=n}^{J(n)} \alpha_{k,n} (\langle z - p, -(v_k + w_k) - q \rangle + \langle u_k - z, -(v_k + w_k) - q \rangle) \\
&\quad + \sum_{k=n}^{J(n)} \alpha_{k,n} \gamma_k (\langle w_k, q_f \rangle - \langle v_k, q_g \rangle - \langle h_{\gamma_k}(u_k), q \rangle) \\
&\leq \langle z - p, -(\bar{v}_n + \bar{w}_n) - q \rangle + \sum_{k=n}^{J(n)} \alpha_{k,n} d_k (\|v_k\| + \|w_k\| + \|q\|) \\
&\quad + \sum_{k=n}^{J(n)} \alpha_{k,n} \gamma_k (\|w_k\| \|q_f\| + \|v_k\| \|q_g\| + \|v_k\| \|q\| + \|w_k\| \|q\|) \\
&\leq \langle z - p, -(\bar{v}_n + \bar{w}_n) - q \rangle + d_n (\tilde{v}_n + \tilde{w}_n + \|q\|) \\
&\quad + \gamma_n (\tilde{w}_n \|q_f\| + \tilde{v}_n \|q_g\| + \tilde{v}_n \|q\| + \tilde{w}_n \|q\|).
\end{aligned} \tag{15}$$

Letting  $n \rightarrow +\infty$ , since  $(v_n)$  and  $(w_n)$  are bounded sequences in  $E$ , we conclude that  $\langle z - p, -(v + w) - q \rangle \geq 0$ . As  $\nabla f + \partial g \in \mathcal{M}$ , this implies that  $(z, (v + w)) \in \nabla f + \partial g$ .  $\square$

By Lem. 3.5 and Fubini's theorem, there is a  $\lambda_T$ -negligible set s.t. for every  $t$  outside this set,  $v(\cdot, t)$  is an integrable selection of  $H_R(\cdot, z(t))$ . Moreover, as  $v$  is a weak cluster point of  $v_n$  in  $\mathcal{L}_E^{1+\varepsilon/2}$ , it holds that

$$z(t) = z(0) + \int_0^t \int_{\Xi} v(s, u) + w(s, u) \mu(ds) du, \quad (\forall t \in [0, T]).$$

By the above equality,  $z$  is a solution to the DI  $\dot{x} \in H_R(x)$  with initial condition  $z(0) = a^*$ . Denoting by  $\Phi_R(a^*)$  the set of such solutions, this reads  $z \in \Phi_R(a^*)$ . As  $a^* \in \mathcal{K} \cap \text{cl}(\mathcal{D})$ , one has  $z \in \Phi_R(\mathcal{K} \cap \text{cl}(\mathcal{D}))$  where we use the notation  $\Phi_R(S) := \cup_{a \in S} \Phi_R(a)$  for every set  $S \subset E$ . Extending the notation  $d(x, S) := \inf_{y \in S} d(x, y)$ , we obtain that  $d(x_n, \Phi_R(\mathcal{K} \cap \text{cl}(\mathcal{D}))) \rightarrow 0$ . Thus, for every  $\eta > 0$ , we have shown that  $\mathbb{P}^{a_n, \gamma_n}(d(X_{\gamma_n}, \Phi_R(\mathcal{K} \cap \text{cl}(\mathcal{D}))) > \eta) \rightarrow 0$  as  $n \rightarrow \infty$ . We have thus proven the following result:

$$\forall \eta > 0, \lim_{\gamma \rightarrow 0} \sup_{a \in \mathcal{K} \cap \mathcal{D}_{\gamma M}} \mathbb{P}^{a, \gamma}(d(X_\gamma, \Phi_R(\mathcal{K} \cap \text{cl}(\mathcal{D}))) > \eta) = 0.$$



Let  $T > 0$  and  $R > \sup\{\|\Phi(a, t)\| : t \in [0, T], a \in \mathcal{K} \cap \text{cl}(\mathcal{D})\}$  (the latter quantity being finite, see *e.g.* [15]). Consider any solution  $\mathbf{x}$  to the DI  $\dot{\mathbf{x}} \in \mathbf{H}_R(\mathbf{x})$  with initial condition  $a \in \mathcal{K} \cap \text{cl}(\mathcal{D})$ . Consider the set  $F = \{t \in [0, T], \mathbf{x}(t) = \Phi(a, t)\}$ . Then,  $0 \in F$ . Let  $\bar{t} = \sup F$  and assume that  $\bar{t} < T$ . Since  $F$  is closed,  $\bar{t} \in F$  and we have  $\|\mathbf{x}(\bar{t})\| < R$ , hence there exists  $\varepsilon > 0$  such that  $\|\mathbf{x}(t)\| < R$  for all  $t \in [\bar{t}, \bar{t} + \varepsilon]$ . Then,  $\mathbf{x}$  and  $\Phi(a, \cdot)$  are solutions to the DI  $\dot{\mathbf{x}} \in \mathbf{H}(\mathbf{x})$  over  $[\bar{t}, \bar{t} + \varepsilon]$  and  $\mathbf{x}(\bar{t}) = \Phi(a, \bar{t})$ , therefore  $\mathbf{x}(t) = \Phi(a, t)$  for all  $t \in [\bar{t}, \bar{t} + \varepsilon]$ . Hence,  $\bar{t} + \varepsilon \in F$ . Finally,  $\bar{t} = T$  and  $F = [0, T]$ . By the same arguments as in [13, Section 4 - End of the proof], Theorem 3.1 follows.

### 3.2 Stability

**Theorem 3.6.** Assume hypotheses H1 and H2. Let  $x_\star \in Z(\partial G + \nabla F)$  that admits a  $\mathcal{L}^2$  representation. Then, there exists  $\alpha, C > 0$  such that

$$\mathbb{E}_n^{\gamma, a} \|x_{n+1} - x_\star\|^2 \leq \|x_n - x_\star\|^2 - \alpha\gamma(F^\gamma(x_n) + G^\gamma(x_n)) + \gamma C. \quad (16)$$

for  $\gamma$  enough close to 0.

*Proof.* To simplify notations, we now omit the dependence in  $(s, t)$  in the sequel and write  $u_n := u_n(t)$ ,  $v_n := v_n(s, t)$ ,  $w_n := w_n(s, t)$ ,  $h_\gamma := h_\gamma(s, \cdot)$ ,  $\partial g := \partial g(s, \cdot)$ ,  $\nabla f := \nabla f(s, \cdot)$ ,  $\gamma := \gamma_n$ ,  $\text{prox}_{\gamma f} := \text{prox}_{\gamma f(s, \cdot)}$ ,  $\nabla f_\gamma := \nabla f_\gamma(s, \cdot)$ ,  $\mathbf{z} := \mathbf{z}(t)$ . Moreover, we write  $\widetilde{\text{prox}}_{\gamma g}(x) := \text{prox}_{\gamma g(s, \cdot)}(x - 2\gamma \nabla f_\gamma(s, x))$  and  $\widetilde{\nabla} g_\gamma := \nabla g_\gamma(s, x - 2\gamma \nabla f_\gamma(s, x))$ , for all  $x \in E$ .

By assumption, there exists a  $\mathcal{L}^2$  representation  $(\varphi, \psi)$  of  $x_\star$ . We write

$$\begin{aligned} \langle \nabla f_\gamma(x), x - x_\star \rangle &= \langle \nabla f_\gamma(x) - \psi, x - x_\star \rangle + \langle \psi, x - x_\star \rangle \\ &= \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle + \langle \nabla f_\gamma(x) - \psi, \gamma \nabla f_\gamma(x) \rangle \\ &\quad + \langle \psi, x - x_\star \rangle \\ &= \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle - \gamma \langle \psi, \nabla f_\gamma(x) \rangle \\ &\quad + \langle \varphi, x - x_\star \rangle + \gamma \|\nabla f_\gamma(x)\|^2. \end{aligned}$$

We also write

$$\begin{aligned} \langle \widetilde{\nabla} g_\gamma(x), x - x_\star \rangle &= \langle \widetilde{\nabla} g_\gamma(x) - \varphi, x - x_\star \rangle + \langle \varphi, x - x_\star \rangle \\ &= \langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle + \langle \widetilde{\nabla} g_\gamma(x) - \varphi, x - \widetilde{\text{prox}}_{\gamma g}(x) - 2\gamma \nabla f_\gamma(x) \rangle \\ &\quad + \langle \varphi, x - x_\star \rangle + \langle \widetilde{\nabla} g_\gamma(x) - \varphi, 2\gamma \nabla f_\gamma(x) \rangle \\ &= \langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle - \gamma \langle \varphi, \widetilde{\nabla} g_\gamma(x) \rangle \\ &\quad + 2\gamma \langle \widetilde{\nabla} g_\gamma(x), \nabla f_\gamma(x) \rangle + \langle \varphi, x - x_\star \rangle + \gamma \|\widetilde{\nabla} g_\gamma(x)\|^2 - 2\gamma \langle \varphi, \nabla f_\gamma(x) \rangle. \end{aligned}$$

Hence,

$$\begin{aligned} &\langle \nabla f_\gamma(x) + \widetilde{\nabla} g_\gamma(x), x - x_\star \rangle \\ &= \langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle + \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle \\ &\quad + \gamma \|\widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x)\|^2 - \gamma \left\{ \langle \varphi + \psi, \nabla f_\gamma(x) \rangle + \langle \varphi, \widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x) \rangle \right\} \\ &\quad + \langle \varphi + \psi, x - x_\star \rangle \end{aligned} \quad (17)$$

By expanding

$$\|x_{n+1} - x_\star\|^2 = \|x_n - x_\star\|^2 + 2\langle x_{n+1} - x_n, x_n - x_\star \rangle + \|x_{n+1} - x_n\|^2,$$

we obtain

$$\begin{aligned} \|x_{n+1} - x_\star\|^2 &= \|x_n - x_\star\|^2 - 2\gamma \langle \widetilde{\nabla} g_\gamma(x_n), x_n - x_\star \rangle - 2\gamma \langle \nabla f_\gamma(x_n), x_n - x_\star \rangle \\ &\quad + \gamma^2 \|\widetilde{\nabla} g_\gamma(x_n) + \nabla f_\gamma(x_n)\|^2. \end{aligned} \quad (18)$$

Using (17), we obtain

$$\begin{aligned}\|x_{n+1} - x_\star\|^2 &= \|x_n - x_\star\|^2 \\ &\quad - 2\gamma \left\{ \langle \widetilde{\nabla} g_\gamma(x_n) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x_n) - x_\star \rangle + \langle \nabla f_\gamma(x_n) - \psi, \text{prox}_{\gamma f}(x_n) - x_\star \rangle \right\} \\ &\quad - \gamma^2 \|\widetilde{\nabla} g_\gamma(x_n) + \nabla f_\gamma(x_n)\|^2 + 2\gamma^2 \left\{ \langle \varphi + \psi, \nabla f_\gamma(x_n) \rangle + \langle \varphi, \widetilde{\nabla} g_\gamma(x_n) + \nabla f_\gamma(x_n) \rangle \right\} \\ &\quad - 2\gamma \langle \varphi + \psi, x_n - x_\star \rangle\end{aligned}$$

where we used  $\|a + b\|^2 = \|a\|^2 + \|b\|^2 + 2\langle a, b \rangle$ . Then, since  $2\langle a, b \rangle \leq \|a\|^2/2 + 2\|b\|^2$ ,

$$\begin{aligned}\|x_{n+1} - x_\star\|^2 &\leq \|x_n - x_\star\|^2 \\ &\quad - 2\gamma \left\{ \langle \widetilde{\nabla} g_\gamma(x_n) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x_n) - x_\star \rangle + \langle \nabla f_\gamma(x_n) - \psi, \text{prox}_{\gamma f}(x_n) - x_\star \rangle \right\} \\ &\quad - \gamma^2/2 \|\widetilde{\nabla} g_\gamma(x_n) + \nabla f_\gamma(x_n)\|^2 + \gamma^2/2 \|\nabla f_\gamma(x_n)\|^2 \\ &\quad + 2\gamma^2 \|\varphi\|^2 + 2\gamma^2 \|\varphi + \psi\|^2 - 2\gamma \langle \varphi + \psi, x_n - x_\star \rangle.\end{aligned}\tag{19}$$

Observe that the term between the braces at the right hand side of the last inequality is nonnegative thanks to the monotonicity of  $\nabla f(s, \cdot)$  and  $\partial g(s, \cdot)$ .

Let  $x \in E$ . By the convexity of  $g_\gamma$  and  $f_\gamma$ , we have

$$g_\gamma(x - 2\gamma \nabla f_\gamma(x)) - g_\gamma(x_\star) \leq \langle \widetilde{\nabla} g_\gamma(x), x - 2\gamma \nabla f_\gamma(x) - x_\star \rangle\tag{20}$$

and

$$f_\gamma(x) - f_\gamma(x_\star) \leq \langle \nabla f_\gamma(x), x - x_\star \rangle.\tag{21}$$

Using the  $1/\gamma$ -Lipschitz continuity of  $\nabla g_\gamma$  we have

$$g_\gamma(x) - g_\gamma(x - 2\gamma \nabla f_\gamma(x)) \leq \langle \widetilde{\nabla} g_\gamma(x), 2\gamma \nabla f_\gamma(x) \rangle + 2\gamma \|\nabla f_\gamma(x)\|^2.\tag{22}$$

Summing the inequalities (20), (21) and (22) we obtain

$$f_\gamma(x) - f_\gamma(x_\star) + g_\gamma(x) - g_\gamma(x_\star) \leq \langle \nabla f_\gamma(x) + \widetilde{\nabla} g_\gamma(x), x - x_\star \rangle + 2\gamma \|\nabla f_\gamma(x)\|^2\tag{23}$$

Using (17),

$$\begin{aligned}& f_\gamma(x) - f_\gamma(x_\star) + g_\gamma(x) - g_\gamma(x_\star) \\ &\leq 2\gamma \|\nabla f_\gamma(x)\|^2 \\ &\quad + \langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle + \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle \\ &\quad + \gamma \|\widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x)\|^2 - \gamma \left\{ \langle \varphi + \psi, \nabla f_\gamma(x) \rangle + \langle \varphi, \widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x) \rangle \right\} \\ &\quad + \langle \varphi + \psi, x - x_\star \rangle \\ &\leq \frac{3}{2} \gamma \|\nabla f_\gamma(x)\|^2 \\ &\quad + \langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle + \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle \\ &\quad + \frac{3}{2} \gamma \|\widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x)\|^2 + \langle \varphi + \psi, x - x_\star \rangle + \frac{\gamma}{2} \|\varphi\|^2 + \frac{\gamma}{2} \|\varphi + \psi\|^2 \\ &\leq -\frac{3}{2} \gamma \|\nabla f_\gamma(x)\|^2 + 3 \left\{ \gamma \|\nabla f_\gamma(x)\|^2 - \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle \right\} \\ &\quad + 6 \left\{ \langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle + \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle \right\} \\ &\quad + \frac{3}{2} \gamma \|\widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x)\|^2 + \langle \varphi + \psi, x - x_\star \rangle + \frac{\gamma}{2} \|\varphi\|^2 + \frac{\gamma}{2} \|\varphi + \psi\|^2\end{aligned}$$

Since  $\langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle$  and  $\langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle$  are nonnegative. Using  $\psi = \nabla f(x_\star)$ ,  $\nabla f_\gamma(x) = \nabla f(\text{prox}_{\gamma f}(x))$  and Assumption H2, there exists by Baillon-Haddad theorem  $c > 0$  such that  $c\|\nabla f_\gamma(x) - \psi\|^2 \leq \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle$ . Then,

$$-\langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle \leq -c\|\nabla f_\gamma(x) - \psi\|^2 \leq -c/2\|\nabla f_\gamma(x)\|^2 + c\|\psi\|^2.$$

If  $\gamma < c/2$  we finally have

$$\begin{aligned} & f_\gamma(x) - f_\gamma(x_\star) + g_\gamma(x) - g_\gamma(x_\star) \\ & \leq -\frac{3}{2}\gamma\|\nabla f_\gamma(x)\|^2 + 3c\|\psi\|^2 \\ & \quad + 6\left\{\langle \widetilde{\nabla} g_\gamma(x) - \varphi, \widetilde{\text{prox}}_{\gamma g}(x) - x_\star \rangle + \langle \nabla f_\gamma(x) - \psi, \text{prox}_{\gamma f}(x) - x_\star \rangle\right\} \\ & \quad + \frac{3}{2}\gamma\|\widetilde{\nabla} g_\gamma(x) + \nabla f_\gamma(x)\|^2 + \langle \varphi + \psi, x - x_\star \rangle + \frac{\gamma}{2}\|\varphi\|^2 + \frac{\gamma}{2}\|\varphi + \psi\|^2. \end{aligned}$$

Using 19, there exists  $\alpha, C, C' > 0$  such that

$$\begin{aligned} \|x_{n+1} - x_\star\|^2 & \leq \|x_n - x_\star\|^2 \\ & \quad - \alpha\gamma\{f_\gamma(x_n) + g_\gamma(x_n) - f_\gamma(x_\star) - g_\gamma(x_\star)\} \\ & \quad + C\gamma\{\|\varphi\|^2 + \|\psi\|^2 + \|\varphi + \psi\|^2\} + C'\gamma\langle \varphi + \psi, x_n - x_\star \rangle. \end{aligned}$$

Taking the conditional expectation, the last inner product vanishes, and we get the result.  $\square$

**Lemma 3.7.** The following inequalities hold  $F^{\gamma_0}(x) + G^{\gamma_0}(x) \leq F^\gamma(x) + G^\gamma(x) \leq F^{\gamma'}(x) + G^{\gamma'}(x) \leq F(x) + G(x)$  for all  $0 \leq \gamma' \leq \gamma \leq \gamma_0$ . Moreover H3  $\iff F^{\gamma_0} + G^{\gamma_0}$  coercive  $\iff F^{\gamma_0} + G^{\gamma_0}$  coercive.

Given  $k \in \mathbb{N}$ , we denote by  $P_\gamma^k$  the kernel  $P_\gamma$  iterated  $k$  times. The iterated kernel is defined recursively as  $P_\gamma^0(x, dy) = \delta_x(dy)$ , and

$$P_\gamma^k(x, S) = \int P_\gamma^{k-1}(y, S) P_\gamma(x, dy)$$

for each  $S \in \mathcal{B}(E)$ .

**Lemma 3.8.** Let Assumptions H7, H6, and H3 hold true. Then, for all  $\varepsilon > 0$ , there exists  $M > 0$  such that

$$\sup_{\gamma \in (0, \gamma_0]} \sup_{\pi \in \mathcal{I}(P_\gamma)} \pi((\mathcal{D}_{M\gamma})^c) \leq \varepsilon.$$

*Proof.* We start by writing

$$\mathbf{d}(x_{n+1}) \leq \|x_{n+1} - \Pi_{\text{cl}(\mathcal{D})}(x_n)\| \leq \|x_{n+1} - \Pi_{\text{cl}(D(\xi_{n+1}))}(x_n)\| + \|\Pi_{\text{cl}(D(\xi_{n+1}))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\|.$$

On the one hand, we have by Assumption H6 and the nonexpansiveness of the resolvent that

$$\begin{aligned} \bar{\mathbb{E}}_n^{a, \gamma} \|x_{n+1} - \Pi_{\text{cl}(D(\xi_{n+1}))}(x_n)\| & \leq \bar{\mathbb{E}}_n^{a, \gamma} \|\text{prox}_{\gamma g(\cdot, \xi_{n+1})}(x_n) - \Pi_{\text{cl}(D(\xi_{n+1}))}(x_n)\| + \gamma \bar{\mathbb{E}}_n^{a, \gamma} \|\nabla f_\gamma(x_n, \xi_{n+1})\| \\ & \leq C\gamma(1 + F^\gamma(x_n) + G^\gamma(x_n)), \end{aligned}$$

On the other hand, since

$$\|\Pi_{\text{cl}(D(\xi_{n+1}))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\|^2 \leq \mathbf{d}(x_n)^2 - d(x_n, D(\xi_{n+1}))^2 \quad (\text{see (7)}),$$

we can make use of Assumption H7 to obtain

$$\bar{\mathbb{E}}_n^{a, \gamma} \|\Pi_{\text{cl}(D(\xi_{n+1}))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\| \leq (\bar{\mathbb{E}}_n^{a, \gamma} \|\Pi_{\text{cl}(D(\xi_{n+1}))}(x_n) - \Pi_{\text{cl}(\mathcal{D})}(x_n)\|^2)^{1/2} \leq \rho \mathbf{d}(x_n),$$

where  $\rho \in [0, 1)$ . We therefore obtain that  $\bar{\mathbb{E}}_n^{a,\gamma} \mathbf{d}(x_{n+1}) \leq \rho \mathbf{d}(x_n) + C\gamma(1 + F^\gamma(x_n) + G^\gamma(x_n))$ . By iterating, we end up with the inequality

$$\bar{\mathbb{E}}^{a,\gamma}(\mathbf{d}(x_{n+1})) \leq \rho^{n+1} \mathbf{d}(a) + C\gamma \sum_{k=0}^n \rho^{n-k} (1 + \bar{\mathbb{E}}^{a,\gamma}(F^\gamma(x_k) + G^\gamma(x_k))). \quad (24)$$

By taking the expectation and iterating in Th. 3.6,

$$\alpha \sum_{k=0}^n \bar{\mathbb{E}}^{a,\gamma}(F^\gamma(x_k) + G^\gamma(x_k)) \leq \frac{1}{\gamma} \|a - x_\star\|^2 + (n+1)C$$

for all  $n \geq 0$ . Thus, by induction, for all  $k \geq 0$ ,  $\bar{\mathbb{E}}^{a,\gamma}(F^\gamma(x_k) + G^\gamma(x_k)) < \infty$ . By Markov's inequality,

$$\bar{\mathbb{P}}^{a,\gamma}(\mathbf{d}(x_k) \geq M\gamma) \leq \frac{\bar{\mathbb{E}}^{a,\gamma}(\mathbf{d}(x_k))}{M\gamma}$$

for all  $k \in \mathbb{N}$ . Let  $\pi_\gamma \in \mathcal{I}(P_\gamma)$ . From Th. 3.6, and Lem. 3.7 we have

$$\mathbb{E}_n^{\gamma,a} \|x_{n+1} - x_\star\|^2 \leq \|x_n - x_\star\|^2 - \alpha\gamma(F^{\gamma_0}(x_n) + G^{\gamma_0}(x_n)) + \gamma C. \quad (25)$$

for all  $\gamma \in (0, \gamma_0]$ . Using [?] it implies

$$\sup_{\gamma \in (0, \gamma_0]} \sup_{\pi \in \mathcal{I}(P_\gamma)} \pi(F^{\gamma_0} + G^{\gamma_0}) < \infty.$$

In particular, noting that  $\mathbf{d}(x) \leq \|x\| + \|\Pi_{\text{cl}(\mathcal{D})}(0)\|$ , we obtain that  $\sup_{\gamma \in (0, \gamma_0]} \sup_{\pi \in \mathcal{I}(P_\gamma)} \pi(\mathbf{d}) < \infty$ . Let  $\gamma \in (0, \gamma_0]$  and  $\pi \in \mathcal{I}(P_\gamma)$ . Getting back to (24), we have for all  $n \in \mathbb{N}$ ,

$$\begin{aligned} \pi(\{x : \mathbf{d}(x) \geq M\gamma\}) &= \bar{\mathbb{P}}^{\pi,\gamma}(\mathbf{d}(x_{n+1}) \geq M\gamma) \\ &\leq \frac{\bar{\mathbb{E}}^{\pi,\gamma}(\mathbf{d}(x_{n+1}))}{M\gamma} \\ &\leq \rho^{n+1} \frac{\pi(\mathbf{d})}{M\gamma} + \frac{C}{M} \sum_{k=0}^n \rho^{n-k} (1 + \bar{\mathbb{E}}^{\pi,\gamma}(F^{\gamma_0}(x_k) + G^{\gamma_0}(x_k))) \\ &= \rho^{n+1} \frac{\pi(\mathbf{d})}{M\gamma} + \frac{C}{M} \sum_{k=0}^n \rho^{n-k} (1 + \pi(F^{\gamma_0} + G^{\gamma_0})) \\ &\leq \rho^{n+1} \frac{C}{M\gamma} + \frac{C}{M}. \end{aligned}$$

By making  $n \rightarrow \infty$ , we obtain that  $\pi((\mathcal{D}_{M\gamma})^c) \leq C/M$ , and the proof is concluded by taking  $M$  as large as required.  $\square$

**Lemma 3.9.** Let the assumptions of the statement of Th. 3.1 hold true. Assume that for all  $\varepsilon > 0$ , there exists  $M > 0$  such that

$$\sup_{\gamma \in (0, \gamma_0]} \sup_{\pi \in \mathcal{I}(P_\gamma)} \pi((\mathcal{D}_{M\gamma})^c) \leq \varepsilon. \quad (26)$$

Then, as  $\gamma \rightarrow 0$ , any cluster point of  $\mathcal{I}(\mathcal{P})$  is an element of  $\mathcal{I}(\Phi)$ .

*Proof.* See [?]  $\square$

### 3.3 Proof of Th. 2.1

Assume H1-H6. By [?],  $\bigcup_{\gamma \in (0, \gamma_0]} \mathcal{I}(P_\gamma)$  is tight and by Lem. 3.8 and Lem. 3.9 any cluster point of  $\mathcal{I}(\mathcal{P})$  is an element of  $\mathcal{I}(\Phi)$  as  $\gamma \rightarrow 0$ .

vérifier ce point. On a vraiment besoin de vérifier les intégrabilités?

**Theorem 3.10.** Assume that  $f_v(\cdot, \theta_v)$  and  $g(\cdot, \xi)$  are a.s convex, that there exists  $L > 0$  such that  $f(\cdot, \xi)$  is a.s  $L$ -smooth and that  $\nabla f(\bar{x}, \xi) \in \mathcal{L}^2$  for one  $\bar{x}$ . Besides, assume  $F + G$  coercive and that the function  $x \mapsto \partial_0 g_{\{v,w\}}(x_v, x_w)$  is bounded over compact sets. Finally, we assume that  $\sum_{\substack{v < w \\ \{v,w\} \in E}} d(x, D_{\{v,w\}}) \geq d(x)$  and

$$\int \left( \|\nabla f_\gamma(s, x)\| + \frac{1}{\gamma} \|\text{prox}_{\gamma g(s, \cdot)}(x) - \Pi_{\text{cl}(D(s))}(x)\| \right) \mu(ds) \leq C(1 + |F^\gamma(x) + G^\gamma(x)|).$$

Then, if  $\arg \min F + G \neq \emptyset$ , for all  $\varepsilon > 0$ ,

$$\limsup_{n \rightarrow \infty} \frac{1}{n+1} \sum_{k=0}^n \mathbb{P} \left( d(u_\gamma^{(k)}, \arg \min(F + G)) > \varepsilon \right) \xrightarrow{\gamma \rightarrow 0} 0.$$

where we wrote explicitly the dependance of  $u^{(k)}$  on  $\gamma$ .

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