

NONLINEAR EVOLUTION EQUATIONS THAT ARE NON-LOCAL IN SPACE AND TIME

GASTON BELTRITTI AND JULIO D. ROSSI

ABSTRACT. We deal with a nonlocal nonlinear evolution problem of the form

$$\iint_{\mathbb{R}^n \times \mathbb{R}} J(x-y, t-s) (v(y, s) - v(x, t))^{p-2} (v(y, s) - v(x, t)) \, dy \, ds = 0$$

for $(x, t) \in \mathbb{R}^n \times [0, \infty)$. Here $p \geq 2$, $J : \mathbb{R}^{n+1} \rightarrow \mathbb{R}$ is a nonnegative kernel, compactly supported inside the set $\{(x, t) \in \mathbb{R}^{n+1} : t \geq 0\}$ with $\iint_{\mathbb{R}^n \times \mathbb{R}} J(x, t) \, dx \, dt = 1$ and v stands for an extension of a given initial value f , that is,

$$v(x, t) = \begin{cases} v(x, t) & t \geq 0, \\ f(x, t) & t < 0. \end{cases}$$

For this problem we prove existence and uniqueness of a solution. In addition, we show that the solutions approximate viscosity solutions to the local nonlinear PDE $[\nabla u]^{p-2} u_t = \Delta_p u$ when the kernel is rescaled in a suitable way.

1. INTRODUCTION

Our main goal in this paper is the study of nonlinear evolution problems that are nonlocal both in space and time. Let $F(x) = |x|^{p-2}x$ be a power type nonlinearity and let $J : \mathbb{R}^{n+1} \rightarrow \mathbb{R}$, a nonnegative, continuous kernel, compactly supported in the set $\{(x, t) \in \mathbb{R}^{n+1} : t \geq 0\}$ with $\iint_{\mathbb{R}^n \times \mathbb{R}} J(x, t) \, dx \, dt = 1$. We fix an initial condition $f \in L^\infty(\mathbb{R}^n \times (-\infty, 0))$. Our aim is to look for solutions to the nonlocal nonlinear evolution problem

$$(P(J, f)) \quad \iint_{\mathbb{R}^n \times \mathbb{R}} J(x-y, t-s) P(v(y, s) - v(x, t)) \, dy \, ds = 0$$

for $(x, t) \in \mathbb{R}^n \times [0, \infty)$ where we denoted by v the extension by f for $t < 0$ of a function v defined for $t \geq 0$, that is,

$$v(x, t) = \begin{cases} v(x, t) & t \geq 0, \\ f(x, t) & t < 0. \end{cases}$$

This paper can be viewed as a natural continuation of [1] where the linear case $p = 2$ was considered. Notice that here a solution u verifies a nonlinear mean value formula given by $P(J, f)$.

Our first result deals with existence and uniqueness of solutions. We denote by $\tilde{\mathcal{C}}$ the set of uniform continuous functions, and $L^\infty(f)$ stands for the set of bounded functions with norm less or equal than $\|f\|_{L^\infty(\mathbb{R}^n \times (-\infty, 0))}$.

Theorem 1. *Let $J : \mathbb{R}^{n+1} \rightarrow \mathbb{R}$ be, nonnegative, continuous and compactly supported in the set $\{(x, t) \in \mathbb{R}^{n+1} : t \geq 0\}$, with $\iint_{\mathbb{R}^n \times \mathbb{R}} J(x, t) \, dx \, dt = 1$. Let $f \in L^\infty(\mathbb{R}^n \times (-\infty, 0))$. Then, there exists a unique $u \in \tilde{\mathcal{C}} \cap L^\infty(f)(\mathbb{R}^n \times [0, \infty))$ that solves $P(J, f)$.*

We will use the notation u for a solution with initial datum f and we will say that u solves the problem $P(J, f)$. Note that here we assumed that the kernel is nonnegative and integrable (singular kernels are out of the scope of this paper). This fact together with the choice of $f \in L^\infty(\mathbb{R}^n \times (-\infty, 0))$, makes the space $\tilde{\mathcal{C}} \cap L^\infty(f)(\mathbb{R}^n \times [0, \infty))$ a natural choice to look for solutions (remark that the integral that appears in $P(J, f)$ is finite under these conditions). Notice that there is a regularizing effect, for $f \in L^\infty(\mathbb{R}^n \times (-\infty, 0))$ we obtain a uniformly continuous solution, $u \in \tilde{\mathcal{C}} \cap L^\infty(f)(\mathbb{R}^n \times [0, \infty))$. This is due to the fact that we assumed continuity of the kernel J .

We have two different proofs of this existence and uniqueness result. The first one is simpler. We just prove first the result for a class of kernels that are compactly supported in the set $\{(x, t) \in \mathbb{R}^{n+1} : \delta \leq t \leq \delta + \gamma\}$, where δ and γ are positive numbers, (this allows us to easily obtain existence and uniqueness of solutions in the strip $t \in [0, \delta)$ and then in $t \in [\delta, 2\delta)$, etc.). After that we obtain the result for a general kernel by approximating it with kernels in the previously mentioned class. The second proof is more involved technically and is based on a fixed point argument (we include this proof here since we believe that it has independent interest). This fixed point strategy was used for the

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