# GPU Acceleration as an Enabling Factor for Computerized Surgical Guidance In Tumor Treatment

## Executive Summary - NVIDIA GTC 2015 Emerging Companies Summit

### THE COMPANY:

NE Scientific is a **startup company active since 2012 in the field of Computer Science applied to Medicine and Medical Imaging**. The company has been founded by Andrea Borsic (CEO), a former Dartmouth College engineering faculty. During 2014 the company has sought and successfully obtained **funding from the National Cancer Institute for developing a guidance platform for a specific tumor treatment surgical intervention.**

NE Scientific is now fully focused on the development of this product, which has the potential of revolutionizing an entire cancer treatment segment, for which the company has specific and extensive expertise.

### THE TEAM:

The company team is formed by **Andrea Borsic**, CEO and technical lead at NE Scientific LLC. Andrea is a former Dartmouth engineering faculty, holds a PhD, MSc, and BSc degrees in EE, and has 12+ years of professional experience in Medical Imaging and Scientific Computing applied to Medicine.

**Eric Hoffer**, Chief Medical Officer at NES Scientific LLC and Director of Interventional Radiology at the Dartmouth Hitchcock Medical Center, has 20+ years expertize in cancer treatment and in image guided interventions.

### RADIO FREQUENCY ABLATION OF TUMORS:

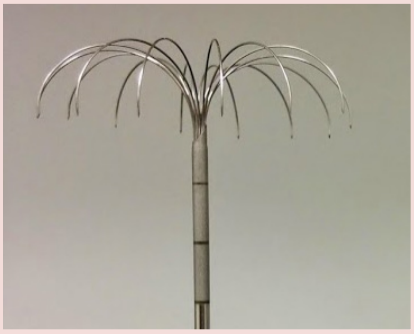

**Figure 1** - Typical electrode for Radio Frequency Ablation: the electrode is formed by a shaft (diameter 3mm) and by an umbrella of tines (diameter of the umbrella 5cm) which can be retracted inside the cannula for insertion into the tumor location, and later expanded to encompass the tumor tissues.

**Radio Frequency Ablation (RFA) of tumors is a surgical intervention that kills malignant tissues**, and which is typically used for treating liver, kidney, and lung cancers. **Tissues are killed by applying Radio Frequency (RF) energy** by means of a needle electrode which is inserted through the skin into the volume of the tumor. A typical needle is shown in Figure 1 and is formed by a main shaft and by retractable tines shaped like an umbrella (diameter 2.5cm to 5cm, depending on the model). The tines are retracted inside the shaft before insertion, and they expand once in positon to encompass the tumor. **The applied RF energy raises the temperature of tissues to 80 / 100 degrees Celsius over the course of 5 to 15 minutes, killing a mass of tissues of a diameter of 2cm to 6cm.** The killed tissues are left in the body and are metabolized over the course of a few weeks.

**RFA is successfully used as an alternative to open surgery, having the advantage of being minimally invasive, and as an alternative to chemotherapy, not having the adverse effects of this treatment option.**

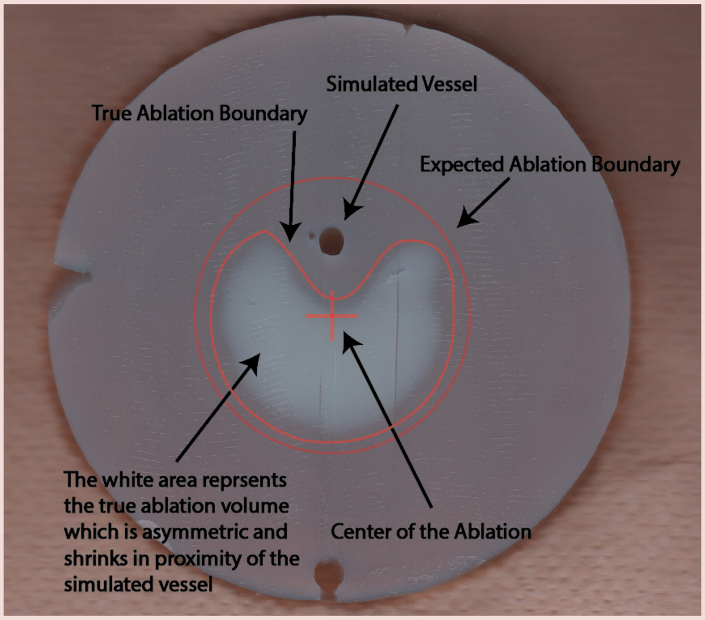


**Figure 2** - Slice of a cylinder made of tissue mimicking gels into which an ablation has been performed. The gel is dyed with a substance that turns white under temperature and which indicates the volume of the tissues that would be killed in a person.
A small round channel was created inside the gel (visible as small round hole at the center-top) and a water flow at a controlled temperature and rate established to simulate the "heat sink" effect of a vessel. The presence of the simulated vessel significantly alters the ablation contour, by shrinking it. The computer model we are developing will account for the effect of vessels in Radio Frequency Ablation. Vessels will be identified from pre-operative CT scans of the patient and fed into the model. The model then will compute the true shape of the kill pattern, which will be used for planning and guiding interventions.

## THE PROBLEM

One shortcoming in RFA is that the kill volume and geometry are affected by the presence of blood vessels and other patient-specific factors. This variability makes it difficult to consistently kill all the malignant tissues, particularly if the tunor is relatively large, as we discuss in more detail in the following.

Blood vessels, which have a lower temperature compared to the tissues heated by RFA (37$^{0}$C versus 80/100$^{0}$C), take heat away from the ablation volume. This "heat sink" effect is made more pronounced by the fact that blood flows, therefore the heat is transported away from the ablation volume by this motion.

By cooling tissues, **vessels, shrink and alter the volume and geometry of the ablation. Physicians base their interventions on printed charts** provided by electrode manufacturers, **wich indicate the expected kill zone for a uniform slab of tissues. As a result they end up killing less tissues then expected. The tissues left untreated are cause of tumor recurrence.** Because of this, the 5-years survival rate of RFA compared to surgery is lower.

Figure 2 shows results from an experiment conducted at NE Scientific LLC to highlight this phenomenon. An ablation was conducted in a cylinder of tissue-mimicking gel. A horizontal slice of this cylinder was cut post-ablation and is shown in the picture. A small tube embedded into the material (which shows as a small round opening at the center-top of the figure) was supplied with water at controlled flow rate and temperature, simulating the presence of a vessel. An ablation was run with an electrode centered in the gel cylinder. The particular material used turns white where temperatures exceed a certain threshold, indicating the ablation volume that would have occurred in human tissues. As it is possible to notice, the true ablation boundary is asymmetric and presents a pronounced shrinkage corresponding to the vessel position. This significantly departs from the ablation geometry in a uniform volume of tissues, which is expected to be circular. This pronounced discrepancy between the expected kill geometry and the true kill geometry makes it difficult for physicians to consistently kill all desired tissues, and therefore to guarantee that no recurrence occurs.

## THE SOLUTION

The **solution we are developing to the above problem consists in a computerized guidance platform, to be used in the operating room**, which works based on these following steps:

Step 1: Identification of vessels in the patient from pre-operative X-Ray CT images
Step 2: The geometry of the vessels is fed into a computer model
Step 3: The electrical / thermal computer model computes temperatures and accounts for the vessels
Step 4: The geometry of the killed tissues is computed from the temperature field
Step 5: The kill geometry is superimposed to the patient CT images and displayed to physicians
Step 6: As the temperatures evolve in time under the application of RF energy, the above steps 3 to 5 are repeated in real-time

Based on the above approach, **physicians will be able to see, in real-time, on a computer screen, an accurate representation of the kill volume and geometry, in the operating room**, as the intervention occurs.
**This visual representation of the kill volume will greatly facilitate complete and consistent narcotization of tumor tissues**, as physicians will be able to visually assess which tissues have been killed and which not.

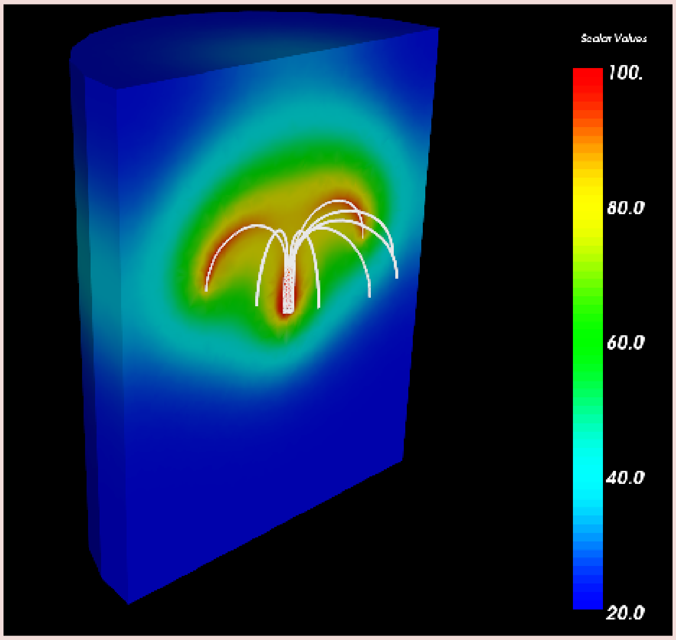


**Figure 3** - Thermal field set in the tissues by a typical Radio Frequency Ablation electrode. This has been computed with a CUDA accelerated RFA Physics Library developed by NE Scientific LLC, and able to compute the temporal evolution of temperatures at a rate 16x faster than real-time. This is a critical factor, as previous works were able to achieve update rates much slower than real-time, preventing therefore the adoption as a guidance tool.

## ROLE OF GPU TECHNOLOGY

While **the above approach has been considered previously by others, computational limitations made this approach unfeasible up to today**.

With the application of radio frequency energy to tissues, the temperature of tissues rises over time. At least 4 updates per second in the computer model are needed to accurately track this temporal evolution and to provide interactive visual information to physicians. **The simulation of an intervention of 10 minutes requires therefore at least 2,400 temperature updates**. Simulation programs use complex three-dimensional Finite Element Models. **This task has been reported to take 3 to 6 hours in previous literature** [1,2,3], as other researchers used off-the-shelf un-optimized, CPU-based computer programs to conduct simulations. **This length of these simulations was therefore incompatible with the use in the operating room.**

**At NE Scientific LLC we have developed a CUDA-accelerated Radio Frequency Ablation Physics Library**, able to solve the coupled electrical thermal problem, to account for vessels, and to predict the kill volume and geometry in real-time. **This simulation library uses custom kernels, the NVIDIA Thrust library, and the NVIDIA CUSP solver. The library is able to update temperatures at a rate of 15 milliseconds on a GTX Titan Black GPU. This rate is 16x faster than real-time, and 300x faster than previous attempts.** These gains were possible thanks to significant computer science and math optimizations deriving from developing the software in-house, and from a significant expertise in the field at NE Scientific LLC. **Figure 3 shows the temperature field computed with the CUDA RFA Physic Library by NE Scientific LLC** for a typical RFA electrode.

**The use of GPU acceleration is therefore a critical and an enabling factor in making this approach to guidance feasible**. We have been able to obtain funding by the National Cancer Institute, and an enthusiastic support for our application, thanks to having been able to demonstrate acceleration of the main algorithms, and thus feasibility for the project

## SIGNIFICANCE

Radio Frequency Ablation is a cancer treatment technology. RFA is preferable to open surgery, as it is minimally invasive, and preferable to chemotherapy, as it acts locally. RFA has unfortunately a lower 5-year survival rate compared to open surgery. This lower survival rate results from cancer recurrence that arises from non-complete narcotization of tumors. The difficulty in consistently achieving complete necrotizations arises from the fact that physicians do not have direct view of the treated area. In RFA a needle is inserted through the skin into the tumor location under CT or Ultrasound guidance. These techniques are able to display the tumor location, but are not well suited to show which tissues have been killed and which not. It is hard therefore to assess whether complete necrotization of a tumor has been achieved, and physicians currrently base thier assesment on printed charts of the expected kill goemetry (which are built considering tissues as uniform, not accouting for vessels, a feature that varies from patient to patient).

**For smaller tumors (e.g. tumors smaller than 2.5cm in diameter) the complete ablation rate is reported to be 87%, while this rate drops to 50% for tumors larger than 3cm [4]. Incomplete necrotization of the malignant tissues results in tumor recurrence.**

RFA is generally used for smaller tumors and for patients with metastatic cancer, where the general health condition of the patient has deteriorated and does not allow open surgery. **Approximately 36,000 RFA interventions**

**are carried out each year in US.**

**The availability of a visualization of the killed tissues, as offered by the system we are developing, will allow physicians to achieve full necrotization of tumor tissues in a easier and more consistent way. This, is hoped, will reduce, or almost eliminate, recurrence due to partial ablations in thousands of patients every year.**

## REFERENCES:


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## NOTICE:


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