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Bringing New Technology to a Complex Market

A market analysis of the VIPS protocol

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Abstract

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University research being adopted by, or transferred to, industry has enabled many of the things we now take for granted. The road from a breakthrough at a university to societal consequences is however a long and winding road full of dead ends and surprising turns. To guide researchers attempting to transfer their discoveries into industry applications there are many support systems, for example the Technology Transfer Offices (TTO) tied to each Swedish university.

After patenting and contracting with a TTO, a first step often consists of finding a company which can utilize the new technology or, similarly, finding an application for the new technology which can benefit a collection of companies. At this stage there are frequently many ideas for applications but a lack of knowledge about how the technology will perform if implemented and how the relevant companies are evaluating investments into new technology.

To solve this, market researchers often divide the intended market into segments and explore the properties of these segments as they relate to the new technology. While there is much research into how this market segmentation and segment exploration is to be done there are no clear and general guidelines. This problem is complex and the answer is contingent on the specifics of the relevant technology, prompting researchers to call for more case studies.

This report reviews, comments on and adds to research on market segmentation methodology when trying to transfer new technology to complex Business to Business markets from the outside. It ends with a model suggestion derived from B2B market segmentation research as well as the start-up literature and field experience. This is done alongside a case study of a start-up based on the VIPS-technology, which is a protocol used in microprocessors. The report also provides a decision basis for VIPS on which to base a future marketing strategy.

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Abstract

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The benefits, as well as the costs, of supporting technology transfer from universities to industry have been well studied and both have been found to be very high. One of the initial stages of many such transfers, B2B market segmentation, have seen much research but has not yet produced any comprehensive guidelines. The complexity of this problem has led some researchers to call for action or case based research.

This report reviews, comments on and adds to research on market segmentation methodology for start-ups based on new technology in complex B2B markets through a case study in the microprocessor industry. It ends with a model suggestion derived from B2B market segmentation literature as well as the start-up literature and field experience. This is done alongside providing a decision basis and general advice for a start-up based on the VIPS-technology, which is a protocol created for use in microprocessors.

The main contributions of this report are considered to be:

- Suggestions on how a start-up based on new technology should discover, investigate and segment potential markets.
- Suggestions on how market segments should be evaluated, chosen and targeted.
- Segmentation of the VIPS market into segments that have similar drivers and would require a similar strategy of approach.
- Evaluation and disqualification of three of the markets that were envisioned by the inventors - HPCs using standardized CPUs, APUs and mobile.
- Identification of a key customer, as well as the formulation of a strategy for how to approach them.
- Identification of the potential for VIPS to simplify chip verification and that there is a market demand for such simplification.
- Highlighting the importance of developing VIPS as a product for needs specific to key markets.

Keywords: B2B marketing, Segmentation, Technology Transfer, Commercialization, Case Study

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Contents

1 Introduction

This section explains the background of the project as well as the purpose of this study and presents an outline for the rest of the report.

1.1 Academic Ventures

A literature review (O´Shea R., 2008) concluded that academic ventures have provided a very powerful set of high-tech companies and according to the OECD(2003), academic entrepreneurs achieving growth is considered an important factor towards a society creating a competitive advantage. To achieve the growth potential of ventures started by academic entrepreneurs, Technology Transfer Offices (TTOs) have been set up to support their efforts through anything from advice, patenting support or funding.

Enormous amounts of money is spent on encouraging and supporting academic entrepreneurship, see for example O'Shea et al. (2008), and in addition to the inherent financial cost of these measures there is also research on related costs of encouraging academic entrepreneurs. For example, (Buesorf G, 2009) showed that researchers produced fewer publications and citations once they took part in a start-up. These and similar studies caused (Toole A., 2010) to be wary of an academic brain drain through spin-off creation. This means that giving a potential academic entrepreneur encouragement and funding is very costly on a societal level and requires a high expected societal value of the potential spin-off.

Steve Blank, a former serial entrepreneur and author of “The Startup Owner’s Manual” turned professor at Stanford, defines a start-up as “a temporary organization searching for a repeatable and scalable business model.” One of the primary questions that need to be answered in order to create a “repeatable and scalable business model” is who the first customers should be and what drives their purchasing decisions. Thus it is important to investigate how a start-up based on new technology should discover, investigate and segment markets as well as how to evaluate and target market segments. In the B2B market segmentation literature there are calls for more case analyses and action based research (Cortez R., 2020). This is exactly what this report does. It does so through a case study of a USO based on a technology called VIPS and also investigates these questions for the USO with the same name.

1.2 Background of VIPS

VIPS is a cache coherence protocol for processors developed by Stefanos Kaxiras and Alberto Roos at Uppsala University. The protocol is an instruction set that defines how a microprocessor deals with data to ensure consistency in its memory locations. The initial findings took place in late 2011 when the two researchers were involved in a project called HEAP, funded by the European Union. Shortly after the discovery the scientists realized that the scope of VIPS was much larger than just HEAP and started developing it further outside of the project. As of spring 2013 the invention is still just a theoretical model that has yet to be verified, but three patent applications have been filed. The goal of the scientists is to verify and commercialize their findings. The project is still at an initial phase and no company has yet been formed. However, a first evaluation of the invention has been initiated in cooperation with the semiconductor manufacturer STMicroelectronics who were a partner of the HEAP project. Also, preliminary discussions with other semiconductor companies have been conducted.

Parallel with the refinement and verification of the technology, the scientists aim to identify and approach potential customers. For this reason the researchers contacted Uppsala Universitet Projekt AB (UU Projekt), which helps research projects from the university to commercialize new discoveries. A partnership was formed in early 2012 where UU Projekt started funding VIPS as well as help with the sales, marketing and patent processes. Upon a request from UU Projekt, a team of three master students were asked to assist with a market analysis. The goal was to get a clearer view of who their customers could be and what they primarily value.

1.3 Purpose

The purpose of this report is to answer the questions (1) “how should one investigate and describe a complex B2B market for a new technology”, (2) “how does one segment such a market?” and (3) “how does one evaluate the segments?” The report seeks to answer these questions through a case study of VIPS and also intends to provide a decision basis for VIPS to select a first market and choose a method of approach.

Based on these facts, a unique selling point (USP) of VIPS will be proposed along with a suggestion of a strategy for how to enter the chosen market segment. Together, these two parts will be used to present practical advice for the future development of VIPS and similar companies.

1.4 Outline of report

This report is divided into eight chapters, not including this introduction. The first chapter establishes a theoretical framework for the report, focusing on both how to segment B2B markets in general and on the special case of a high-tech USO.

The second part details the methodology used for the empirical study, including how literature studies and interviews have been organized. It explains how different possible applications of the technology were found and how they were evaluated.

Then following two chapters explain the background of the project in more detail. The first of those gives an in-depth description of the invention itself and its features. It ex-plains how computer systems are designed and what cache coherence is. Here there is also a comparison between VIPS and the older coherence protocol MESI.

The second background section is based mainly on interviews with the scientists and explores how the project came to be and what have been done so far regarding the commercialization process. The goal is to give an accurate description of the current situation and what motivates the people involved to continue their work.

The main part of the report is the following chapter which lists the findings that have been made. This starts with a market overview that explains how the semiconductor industry works on a general level. After that comes a segmentation of the market for VIPS. A discussion is then held about how these should be evaluated, given the technical questions that have to be answered and the identified market drivers. Some market segments are then chosen and these segments are examined in more detail.

2 Theory

This section outlines important theoretical frameworks used to analyze university spin outs, disruptive innovations and theory on how to segment industrial markets and select segments. This will be used to help VIPS see their challenges in a wider perspective and to answer the questions asked in the introduction.

2.1 Choosing a theoretical framework

The main part of this report will focus on testing methodologies for finding viable applications for the VIPS technology using empirical data regarding technological feasibility and market drivers. A theoretical framework was constructed partly to guide this process and partly to position this case study as an addition to the relevant literature. This framework is primarily grounded in business-to-business market segmentation theory and two different theories regarding adaption of technological innovations on mainstream markets.

Since another aspect of the study is centered on the researchers themselves and the entrepreneurial process, a second framework has been set up to analyze VIPS from the perspective of academic research on university spinouts. This framework guides the finishing recommendations and allows for a wider perspective from which to view VIPS' future challenges.

2.2 Business to Business Market Segmentation

In this section we provide an overview of the research and diver deeper into the most relevant research in B2B market segmentation.

2.2.1 Overview

In a systematic review of B2B market segmentation research (Roberto Mora Cortez, 2020) conclude that the research has not yet empirically demonstrated the value of B2B market segmentation nor has it produced any comprehensive guidelines for developing robust market segments. They also conclude that “while publication in B2B journals seems steady over time, the trend lines for the overall sample … are clearly downward” signifying a reduced interest in B2B market segmentation research in the wider market research community. In closing they remark that “Action and case based research emerge as appropriate approaches to account for the conceptual, applied, and technological challenges in the segmentation task and to validate in detail the consequences of a successful implementation.”

In their literature review they show that “B2B market segmentation is a continuous process that should be disaggregated into four concrete, intertwined stages: (1) pre-segmentation, (2) segmentation, (3) implementation, and (4) evaluation.” They describe the state of research pertaining to each of these stages shown in figure 1.

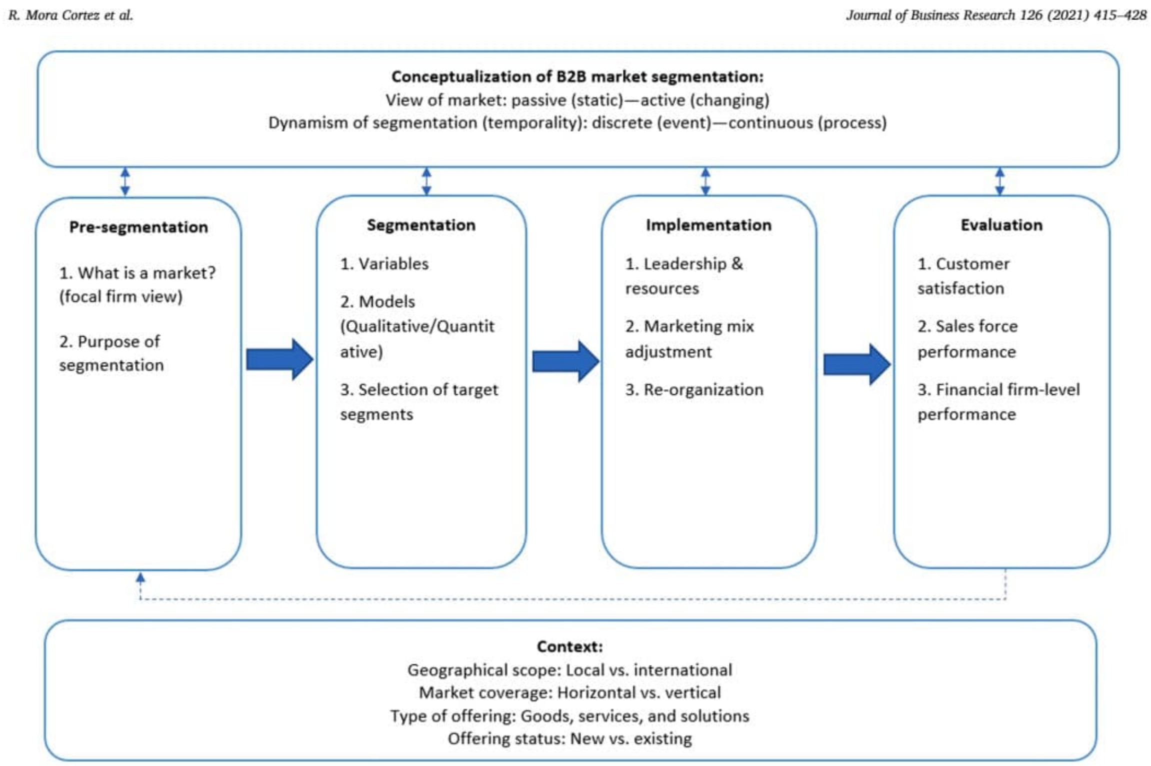

Fig 1. Overview of B2B market segmentation in marketing strategy (Cortez R., 2020)

They note that different researchers conceptualize market segmentation differently. They may view the market as either static or dynamic and the segmentation itself as either a discrete event or as a continuous process. They also define markets differently, whether supply-side, demand-side, or technology based. While demand-side is the most common there are re-searchers who focus on supply characteristics such as capabilities and the nature of the organ-ization. Others argue for a balanced mix of these perspective. There is also a technology-based perspective which helps firms that develop new technology de-scribe the market as technologies comparable to the new technology being developed. The different purposes for segmentation that have been stated by researchers is described as (1) marketing strategy, (2) identifying target segments and planning future product offers, (3) management of customer future value potential, or (4) improved salesperson performance.

Segmentation variables considered by researchers have shifted over the decades from a focus on macro-variables, such as size or location, to micro-variables (i.e. information unique to the customer). Examples of micro variables relevant to this paper that have been considered by researchers are purchasing patterns of sourcing strategy, customer intentions toward collabo-ration and purchasing process.

Models to identify market segments are characterized by (Cortez R., 2020) as based on build-up versus breakdown approaches. Researchers either start with individuals and find commonality which they use to build up market segments, or they start with a market and divide that market using segmentation variables. They claim that “aggregating individual customers is an a posteriori approach (segmentation variables are extracted from a pool generally via statistical analysis) and disaggregating a large market is an a priori approach (segmentation variables and their categories are decided before data are collected).” While most quantitative models are based on a build-up approach, qualitative methods generally propose a breakdown approach.

This claim that disaggregating a large market is an a priori approach may well be true of the articles reviewed by Cortez et al. but it should be noted here that this study disaggregates a large market using segmentation variables which are decided as a response to the data collected.

Criteria for segment selection is referred to as an “attractiveness metric” and are said to help B2B marketers select the right segments. Examples used in the research mentioned in (Cortez R., 2020) are identifiability, substantiality, accessibility, stability, responsiveness, and actionability. (Hlavacek J., 1986) proposes a metric based on (1) market growth potential, (2) The level of market domination by large and powerful competitors, (3) Entry barriers and the ability to reach critical mass by the producer and (4) the value added by the producer. They suggest that value added be determined by a value-in-use estimation, meaning the worth of the producer's product when substituted for the product presently being used by the customer.

According to (Cortez R., 2020) “a synthesis of the implementation literature highlights a view on implementation as the execution of plans, which involves work on the organizational structure.” The overview of implementation research provided by Cortez et al. doesn’t reveal any research as interesting to the case of a USO start up as the literature specifically on USOs or start-ups. This is likely because the execution of a marketing plan and the related change to the organizational structure is core to the USO & start-up literature and the literature on implementations of segments in marketing strategy primarily seems to deal with adjustments to an existing organizational structure. Similarly the evaluation literature is of little interest to this study as this case study ends before evaluation is possible.

2.2.2 Theoretical Foundations of B2B Market Segmentation Research

(Cortez R., 2020) classified 33% of the final sample in their literature review as theoretical, meaning that they purposively inform their theoretical foundation or anchor their conceptual framework or hypothesis development in at least one specific theory. They also examined the theories used by the theoretical articles and found only 6 theories which were applied by more than a single article. Those theories were: Relationship Marketing Theory (4), Organizational Buying Behavior (4), Business Solutions theory (2), Customer Portfolio Theory (2), Customer Value Theory (2), and Equity Theory (2). As these are the theories which have been most frequently applied in B2B market segmentation research we briefly describe them in this section and give examples of their usage in B2B market segmentation literature. We also dive deeper into Relationship Marketing Theory and Organizational Buying Behavior as these have been most commonly used.

(Akalan R., 2021) contains a literature review and attempts to give a consistent definition of Business Solutions. The proposed definition is: “Business solutions are a set of integrated resources and capabilities (i.e., products, services, knowledge) based on a manufacturer’s deep understanding of customer needs and requirements. With business solutions manufacturers take operational responsibility for a specific customer outcome.” It concludes that the field of business solutions has been growing over four decades and is currently in a highly fragmented state. The literature deals with outcomes, benefits, challenges and risks. (Windler K., 2016) attempts to develop and apply a methodology for identifying, assessing and segmenting a market for business solutions. They highlight the difficulty of starting as a solutions supplier without a pre-established relationship with the buyer. This importance of a relationship with the buyer makes business solutions research highly related to relationship marketing theory (Akalan R., 2021).

Portfolio theory was first developed to be used in financial investment decision making but has since been used to analyze product portfolios as well as customer portfolios, where customer portfolio analyses can enhance and promote marketing planning and communication (Droussiotis D., 1994). Viewing customers as parts of a portfolio rather than as individuals allows a marketer to see “the forest instead of the trees”. As an example, (Tarasi C., 2011) uses customer portfolio theory among other things to assess the complementarity/similarity of market segments and explore market segment weights in an optimized portfolio.

(Woodruff, 1997) suggests customer value should be defined as “a customer's perceived preference for and evaluation of those product attributes, attribute performances, and consequences arising from use that facilitate (or block) achieving the customer's goals and purposes in use situations.” In a brief summary of the state of research into customer value theory (Blocker C., 2007) state that value is seen as subjective and relative to competitive offers. Researchers are also said to agree that customers’ value perceptions are dynamic. The dynamic nature of customer value has led researchers to study customer value change which is seen as a theory in its own right.

Equity Theory focuses on input and outcome. As described by Adams in 1965: “inequity exists for a person whenever he perceives that the ratio of his outcomes to inputs and the ratio of others outcomes to others inputs are unequal”. Equity Theory originates in the study of the relationship between employer and employee (Al-Zawahreh A., 2012), but has since been used in many other areas. For example (Ross S., 2017) studies market segmentation based on equity sensitivity and attempts to shed light on why prosocial consumption might occur.

2.2.3 Relationship Marketing Theory

In his paper “Relationship marketing defined? An examination of current relationship marketing definitions”, (Harker M. J., 1999) notes that “attempts to define relationship marketing have been varied and many, neatly reflecting the diverse and socio-political backgrounds of RM scholars”. He finally suggests a definition of Relationship Marketing as “An organization engaged in proactively creating, developing and maintaining committed, interactive and profitable exchanges with selected customers [partners] over time is engaged in relationship marketing”. Relationship marketing theory can then be thought of the studies into activities detailed in the definition.

Business-to-business markets have been described as more uncertain and complex than retail consumer markets which results in increased emphasis on building and maintaining interfirm (B2B) relationships (O'Brien M., 2020). However, even among B2B markets you have variety with some markets being characterized by simple market transactions and others by complex “relationship management approach” (Freytag P., 2001). Natural questions which this section investigates are “which markets are suitable for a relationship approach?”, “what is studied/known about these relationship management approaches?” and “how do market segmentation and segment evaluation work in markets suitable for this relationship approach”.

(Freytag P., 2001) addresses the question of which B2B markets are suitable for relationship marketing. It describes a scale with one end described as “simple market transactions” and the other end being described as “complex relationship management”. On the simple market transactions end of the scale you have suppliers competing on traditional variables such as price, reliability and quality. On the other end of the scale you have complicated relationships with close cooperation, highly adapted products, strong bonds and high switching costs. On the “complex relationship management” side of the scale they suggest a relationship approach which involves treating the customer as a unique entity with individual needs and wants.

As a way to assess the performance of B2B relationships (Lages L., 2005) create a scale that reflects the performance of the relationship marketing process taking five dimensions into account: Relationship policies and practices, trust in the relationship, relationship commitment, mutual cooperation, and satisfaction with the relationship. Marketing to a company with a relationship approach would involve improving on these dimensions. For example a marketing effort in a relationship approach may involve increasing cooperation with a customer or improving policies guiding the relationship.

Market segmentation in a relationship setting may be done for different reasons. According to (O'Brien M., 2020) “firms often rely upon segmentation to better define, advance, and deliver value to their customers.” In other words, the purpose of segmentation can be better service to customers by grouping them based on how they should be treated. If on the other hand the purpose is to identify potential customers and how to market to them then segmentation should “involve segmenting based on such factors as general attitude towards collaboration, amount of adaptation required by supplier or customer and commitment needed” (Freytag P., 2001).

2.2.4 Organizational Buying Behavior

Early studies in organizational behavior described organizational buying as a process within a firm which was influenced by nine constructs (Johnston W., 1996). These are:

1. Environmental factors such as political or technological factors.
2. Organizational factors such as the size and the goals of the buyer.
3. Individual factor pertaining to the persons making the purchasing decisions.
4. Group characteristics within the buying center such as their experiences and the structure of the group.
5. Product factors which describe the product purchased.
6. Seller factors which describe the criteria by which potential sellers are evaluated.
7. Conflict/negotiation factors which describe how disagreements within the buying center are resolved.
8. Informational factors that describe what information is influencing the decision and how such information is acquired.
9. Process factors, or stages factors, which describe the process or the different stages of the buying process.

A review article (Johnston W., 1996) claims that "after 25 years of empirical testing, it appears that these models were correct in proposing that [these factors] significantly affect organizational buying behavior." The article also states that the later literature include four additional constructs. These are:

10. Role stress which describes ambiguities, conflict and expectations faced by the people working in the buying center.
11. Decision rules include formal or informal rules by which suppliers are to be selected.
12. Buyer–seller relationship factors describe the existing relationships the buyer has.
13. Communication networks which describe who the employees at the buying center communicate with.

While these are the constructs that describe the conditions under which buying decisions are made it is important to emphasize that risk perception plays a major role in the final decision (Johnston W., 1996). The perceived risk can be influenced by all the above factors but is mostly related to environmental, organizational or purchase characteristics.

At the beginning of organizational buying behavior studies there was a conception of the buying process as beginning at the moment that they prospective buyer realized the need for a purchase and ending once the purchase was evaluated. However, in later years, the process was seen as continuous and dynamic beginning well before the purchase and extending long after the initial evaluation (Chanler J., 2012).

Another trend is to view organizational buying as an integrated part of design, innovation and marketing processes rather than as a separate event intended to fulfill a need that the buyer already has. This integrated view of the buying process also recognizes that purchases can influence all areas in the buying organization by changing the resources available to the buyer. This concept relates to the diffusion of innovations which has been studied both on the level of individual organizations and as a concept touching multiple organizations or even multiple industries (Chanler J., 2012).

Another trend in recent literature identified in (Chanler J., 2012) deals with the connection between knowledge management and organizational buying in a changing informational landscape. There has also been an increased focus on relationships in organizational buying literature where scholars are frequently looking at the borders of any given organization as fluent and non-discrete. This is a response to a trend in industry to outsource important functions that are not directly related to the core competencies of the business. For example, in the microprocessor industry there are many actors that design and sell chips but have outsourced production. In such cases it makes sense to view the border between the designer/seller and the manufacturer as porous and dynamic.

(Lord K., 2002) applies organizational buying behavior theory to a segmentation problem. They attempt to give guidance on how businesses should design their web page to appeal to perspective buyers. They segment organizational buying centers based on their web-based information gathering preferences and habits. Through cluster analysis of respondents to a survey they are able to find three clusters and find differences in how they view internet research but not in the type of information they desire.

2.3 Managing disruptive innovations

When selling to highly innovative technological markets it is important to understand the special industry dynamics that complicate such sales. It is dangerous to assume that everyone in the market will immediately understand the value of a new technology and be ready to invest in implementing that invention.

In “The Innovator’s Dilemma”, (Christensen, 1997) discusses how established firms’ approach what he calls “disruptive technologies” and why many fail to adapt to the changes these bring to an industry. The main point is that traditional management theories are not valid in the face of such disruptions and that companies must be on the alert to identify new technologies as disruptive and choose to handle them in specific ways in order to successfully implement them.

2.3.1 Disruptive Technologies

Christensen’s definition of a disruptive technology is linked to the theory of **resource dependence**, which postulates that it is not truly the managers but rather the customers that are in charge of the future direction of a company. Companies that listen too closely to its customers focus solely on satisfying their, often increasing, demands for better performance and develop new “sustaining” technologies to meet that demand. This often causes the companies to overshoot market demand and develop products that are actually better than what would have satisfied the market. The aspects that define a technology as disruptive are not necessarily related to traditional concepts of technology S-curves, which state that an emerging technology often performs worse than the established one initially only to surpass it later. Christensen’s research instead shows that if the new technology can be evaluated against the parameters that the market require (i.e. being a sustaining technology), large and established firms have no problem allocating enough resources to the development of the technology even though returns might be far into the future. The nature of a disruptive technology is instead that it does not perform well in comparison to established ones, even when predicting into the future. The nature of the dilemma is to realize when a technology might still become "good enough" for the market and in that case if it might bring other advantages that are not currently valued by the customers.

2.3.2 Companies that choose disruptive technologies

If disruptive technologies can be defined as new innovations that cannot fulfil the market's demands and that do not have the potential to ever surpass the old technology, why would any company invest in it? The answer, according to Christensen, is that the new technology can establish itself in a new niche of the market where unconventional properties are required. A successful technology might then improve in the parameters sought by the mainstream market until it is "good enough". Customers will then choose technology based upon other criteria and since the new technology brings something the old did not have they might find that to be a deciding factor. See Figure 2 for an illustration of how such technologies evolve over time.

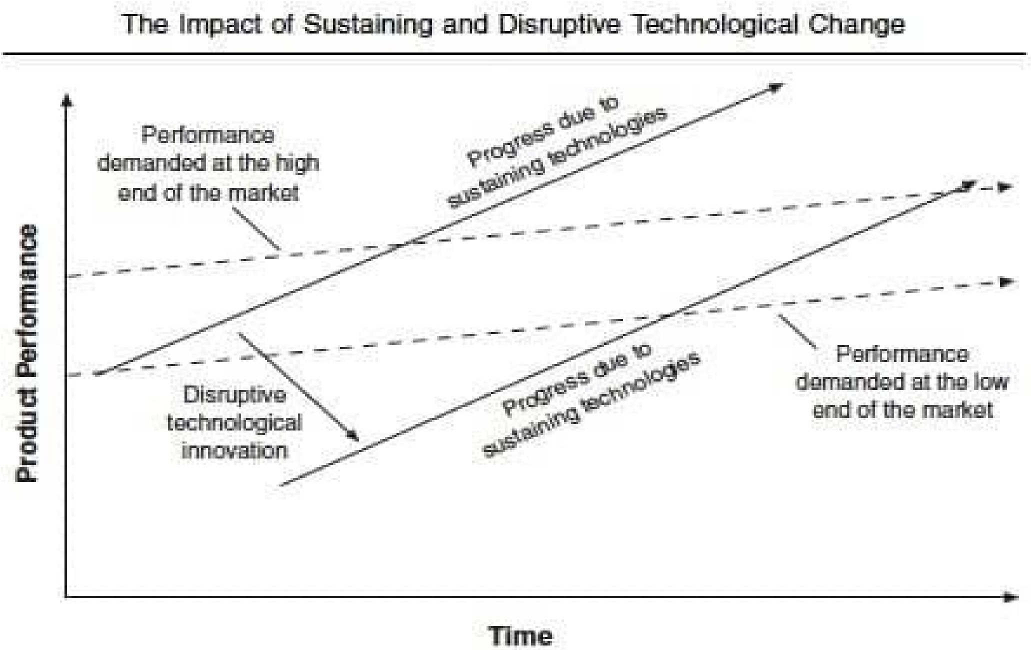

Figure 2. Two technologies developing faster than what the market needs. "Product performance" is here any arbitrary measurement that the mainstream market uses to compare products. (Christensen, 1997)

Established firms often miss these opportunities and disruptive technologies are therefore often brought to market by new entrants that can choose a niche as their primary market in the beginning. In the cases where established firms are successful in adapting disruptive innovations, they usually manage that by removing themselves from the resource dependency. This can be done in different ways but a common way is to develop the technology within a subsidiary or in other ways physically separating the development from the main company.

2.3.3 A disruptive technology within the semiconductor industry

In 2002, Christensen and Bass examined the microprocessor industry and predicted that it was ripe for a disruptive technology to enter the low-end segment (Bass MJ., 2002). That prediction has since then largely been proven to be correct, as can be seen in the case of the competition between Intel and ARM. Intel has long been the market leader, delivering steadily higher performance per dollar to all segments of the computer industry (Paliwal, 2010). In recent years, however, it has been challenged by ARM, even though their initial products did not deliver performance close to that of Intel and others. Instead they focused on low-energy solutions, which became popular in mobile phones and other applications that could not carry a standard processor. The fundamentally different approach created a disruptive technology.

Today, ARM has improved to the point where it is almost as good as Intel in many cases and as a consequence Intel has been struggling to provide its low-end customers with the energy efficient processors they are starting to demand. While this battle for domination is far from over, it seems that Intel will not regain its former position as the one solution for all computing needs. ARM has shown that consumers are interested in other things besides pure performance and this will likely continue to impact the industry permanently. Apart from the rise of alternative processor makers, the theory of the innovators dilemma also predicts a few other things to happen to the industry. As performance, and in time also energy efficiency, reach and surpasses what the market demands it will become less and less important. Reliability, customizability and time-to-market will partly take their places as a technology drivers. In the end, all devices that are manufactured might suffice for the low-end segment and then price will be the only differentiator. This will also open the market more and more to smaller companies that specialize in certain niches (Bass MJ., 2002). Whether or not these predictions have held true will be evaluated in the Market Overview segment later on in the report.

2.3.4 Establishing a foothold in mainstream markets

One of the most prominent models of how new technology is adopted by a market was originally proposed by (Rogers E., 1962) and has been frequently quoted and augmented since. The model divides the market into different groups of customers with different needs and drives. An overview of the model is presented in Figure 4.

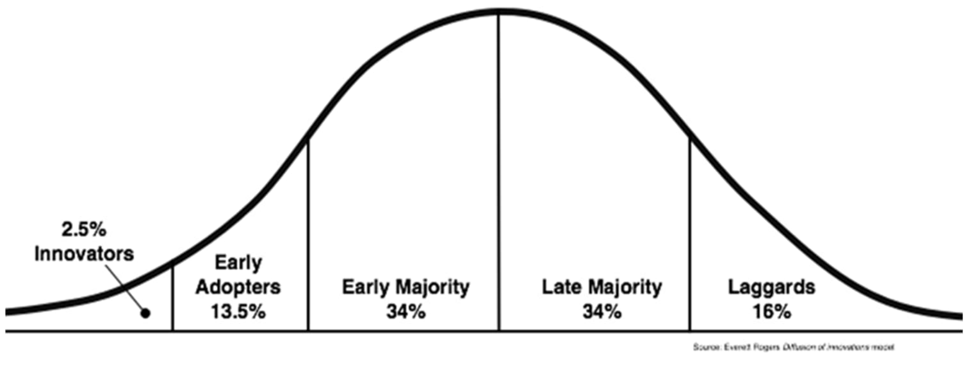

Figure 4. The available customers on a market divided into groups (Rogers E., 1962).

Innovators are **enthusiasts** who appreciate the technology for its own sake and therefore are the first to try new inventions. They want access to the latest and greatest technology, if only to see whether it works or not. Complexity and uncertainty about the product's possible uses are not important. While innovators seldom have huge resources at their disposal, they can still act as gatekeepers for new technology, bringing new ideas into the larger social system.

The second group after innovators are early adopters. They are relatively quick in adopting new technologies, but they do so out of rational reasons: they need to see an actual use for the product. They can also be described as **visionaries**, seeing what benefits a new technology might bring. While they often listen to the innovators and gather information from them, they are not necessarily well positioned to give advice to the later groups. Given the opportunity, they are however often willing to do so.

The early majority are the ones that invest early in new technology, but not before it has matured enough. They are **pragmatists** that need complete packages with fully integrated solutions. Another important aspect is that the early majority often interacts very closely with others within the group and require references when adopting new technologies. Thus, before a company is ready to sell to pragmatists it needs to prove the value of the technology and acquire the alliances needed to give a whole solution to the pragmatists. This means it is very tough to break into a new industry selling to early majority-customers.

The last half of the potential market is made up of groups that are not interested in being early in the adoption of new technology, **conservatives** and **sceptics**. They only want products that work reliably and have gained a clear traction within the market. In the extreme case, they will not invest in new technology unless it is practically impossible not to. They are hard to convince and even harder to reach via advertising (Shilling 2010).

2.3.5 Crossing the Chasm

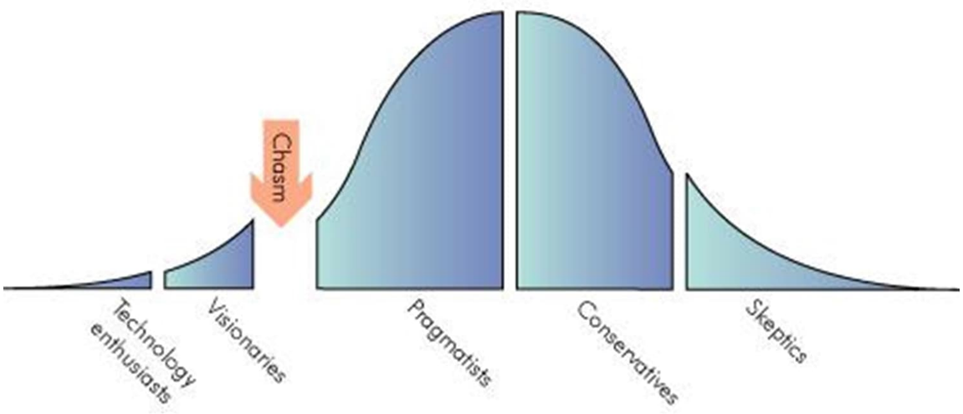

Figure 5. The gaps between the groups, with the one between the second and third groups forming the "chasm" (Moore G., 1991).

In the book "Crossing the Chasm", (Moore G., 1991) discusses what he describes as a crack between each group of technology adopters. By this he wants to stress the difference between the groups and the fact that the way a product or technology is presented in order to be accepted by one group cannot be the same as for the previous group. The crack between visionaries and pragmatists is what Moore calls the chasm since there are several reasons why this step is both exceptionally hard and exceptionally important. The chasm is illustrated in Figure 5.

The problems related to crossing this chasm are many. Pragmatists respond very differently to the communication needed to attract visionaries. Also, the pragmatists tend not to trust references from the left side of the chasm. Thirdly, pragmatists want a whole product with all the supporting infrastructure around it. Lastly, pragmatists are very concerned about who they buy from. They want to buy from market leaders partly because the ecosystem tends to develop around these players.

The first crack between enthusiasts and visionaries is much easier to overcome. The real challenge is formulating a business opportunity around your product. Enthusiasts will be interested simply because it is a new piece of technology whereas the visionaries have business goals in mind. Therefore the communication needs to be changed, but in a very natural way. An academic paper that presents a new piece of technology may be interesting to enthusiasts even if no application is presented, but if this paper also includes envisioned applications, which is certainly the case if the author has any desire to reach commercial success, then it may also be interesting to visionaries. Important to understand when crossing the first crack is that visionaries are looking for orders-of-magnitude improvements and not simple optimizations. The second crack between pragmatists and conservatives are also smaller. The main point here is that the products need to be made simple, cheap and very user friendly.

Companies who are stuck in the chasm are advised to focus on a small market niche and create a whole product especially designed for this market. This advice can be conveyed using an analogy to the D-Day (Moore G., 1991). When the goal is to enter a mainstream market that is dominated by another product, just as Europe was occupied by the Axis, a company must secure a strategic market segment just as the allied forces did on D-Day when they invaded the Normandy beaches. Once that first niche is secured the march onwards into other segments will be much easier.

Another analogy that can be used to find the right kind of market segment to enter first is to imagine a bowling alley (Moore G., 1991). In order to score a strike it is not enough to hit some pins with the ball; those pins must in turn tip other pins. In the same way the niche market must be chosen is such a way that success in that market can be used to enter other markets. Otherwise the company will face a new Normandy beach each time it wishes to expand, ultimately exhausting their resources.

2.4 The development of University Spinout Companies

While the evaluations of potential markets and applications are the primary purpose of this study, a second part will also be to study the scientists and their entrepreneurial journey. In order to do this the background and current situation of the researchers was studied. As inventors within an academic context that have decided to form their own company, they can be compared to many studies that have been made on university spinout companies (**USOs**). These companies are in many ways very different from others in how they proceed from basic research and development to product development and launch. There are also several other ways that academic research can reach the market, as seen in Figure 4.

While studying the evaluation process for potential markets and applications is the primary purpose of this study, a second part will also be to study the scientists and their entrepreneurial journey. In order for this study to also be a case study of the entrepreneurial journey this background and current situation of the researchers was also studied. As inventors within an academic context that have decided to form their own company, they can be compared to many studies that have been made on university spinout companies (**USOs**). These companies are in many ways very different from others in how they proceed from basic research and development to product development and launch. This is just one out of several ways that academic research can reach the market, as seen in Figure 6.

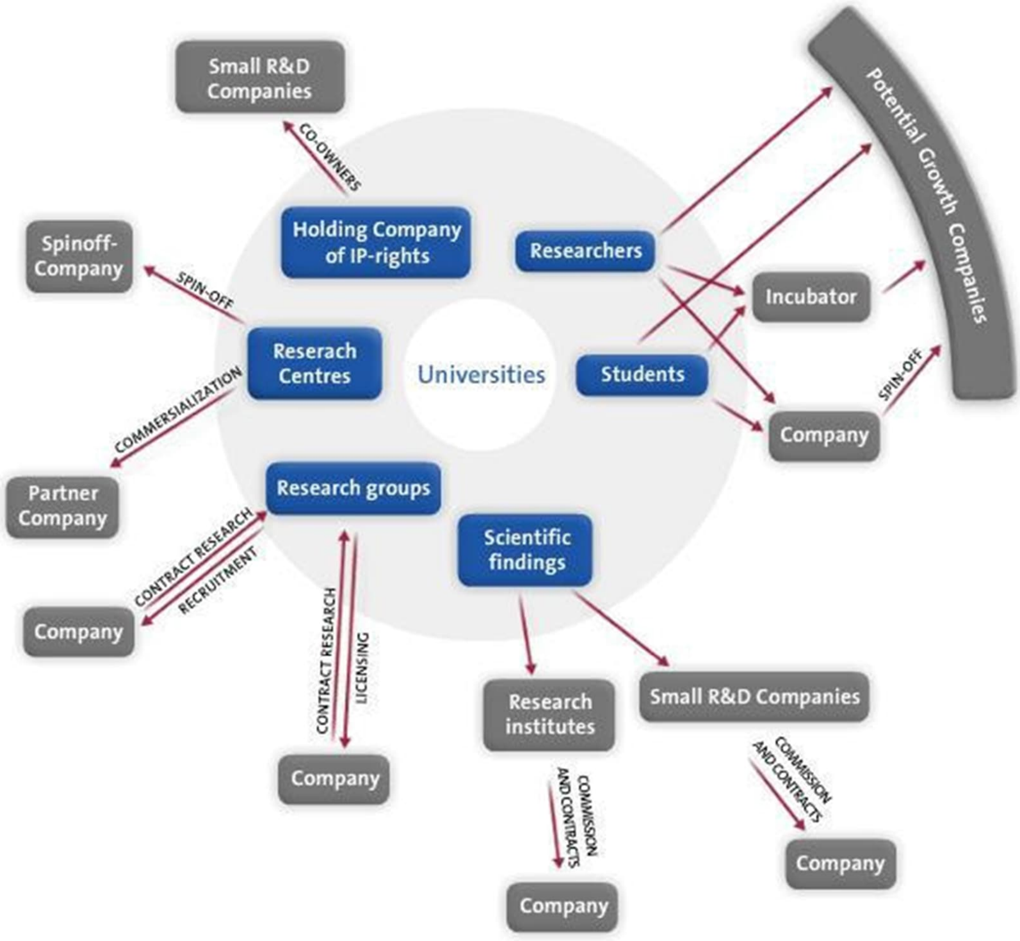

Figure 6. Different ways to reach the market, VIPS is following the way from researcher via an incubator. (Giertz E., 2012)

(Nilsson A., 2010) refers to the process of transferring academic research into industrial applications as a “grey zone” and try to find the driving forces to why some academics choose to pursue a commercialization of their inventions while others do not. They present four main determinants for this:

1. The perceived role of the university – i.e. how the researchers view the role of the university in the society.
2. Supportive infrastructure – technology transfer offices (**TTOs**) or other organizational structures to help the researchers in commercializing attempts.
3. Industrial actor set-up – whether there exist nearby companies that can help develop projects.
4. Networks – the existence of established networks between industry and the university in general, and the researcher in particular.

(Vohora A., 2004) describe the development of USOs as going through a series of phases. These phases can be seen as stages on the spinout’s route from research project to profitable business. (Olofsson C., 2008) expands on this theory and proposes three main roles researchers may adopt when going into entrepreneurial ventures.

The phases that a company must go through are separated by so-called “critical junctures”, and the transition from one phase to the next is dependent on the ability to face them. These junctures characterize inherent conflicts within the USO that prevent development. They are seen as barriers between each phase and require the companies to acquire and re-configure sufficient resources and capabilities to be overcome. Each juncture has its own distinct challenges that need to be resolved to move from one phase to the next.

The order of the phases is linear in that a company has to pass through the previous phase in order to move to the next. However, once at the next phase new conditions may require it to revisit some of the decisions made at an earlier stage. Thus, a part of the development is iterative where the management team continuously has to redefine its operations as the company progresses. A certain path dependency exists though, where major mistakes early in the entrepreneurial process are hard to correct at a later stage. For the success of the USO it is therefore imperative that it early on identifies and acquires lacking resources. A schematic picture of the process is shown in Figure 7. This process is expanded on below, with each phase denoted with a number and each juncture with a letter.

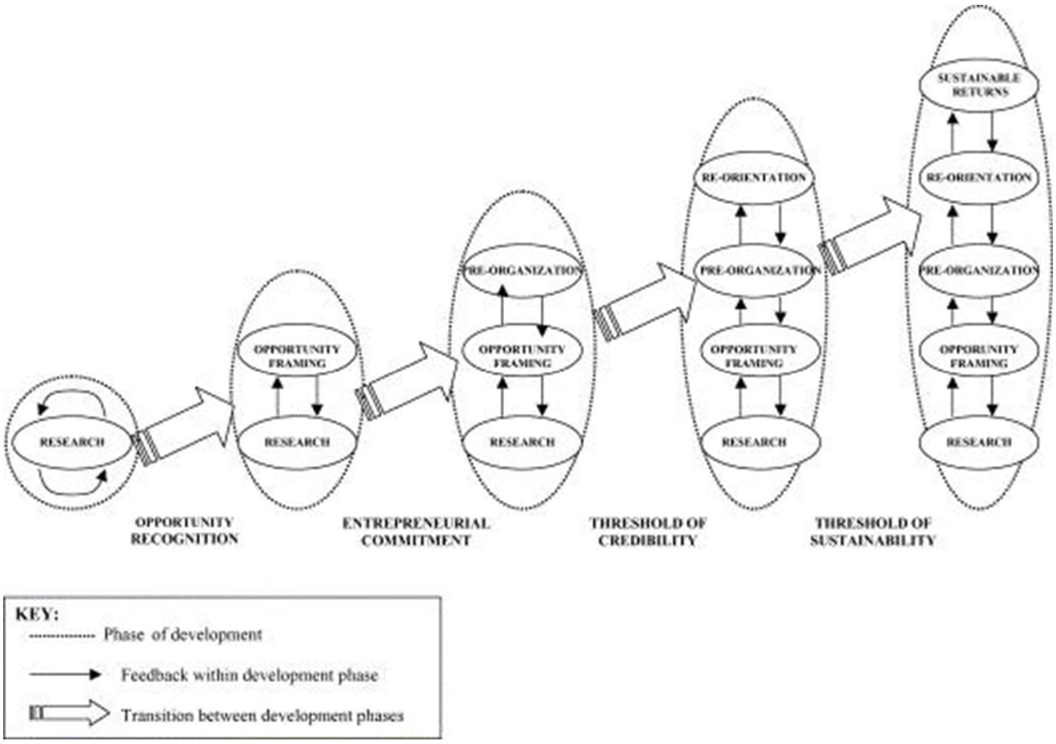

Figure 5. The five phases that a USO has to pass through in order to reach sustainable returns. (Vohora A., 2004)

In the **research phase**, the focus of the inventors is still on research and publication. This phase often goes on for many years with no initial thought on commercialization. **Opportunity recognition** is the match of an unfulfilled market need and a satisfactory solution. The major challenge at this stage is to gather sufficient external knowledge to be able to offer a value proposition aimed at the market rather than further research.

The **opportunity framing** phase is the first step from an identified opportunity to the forming of a new venture. Initially, most of the focus is on validating the technology and finding its potential for use outside the laboratory. Once validated, the framing of the technology's commercial opportunity is refined. This phase has a major impact on the USOs direction and its ability to develop into a sustainable business. Often the opportunities are framed too imprecisely, which cause the USOs to lack focus. This makes it hard to identify, access and acquire the resources that will be required further down the line. Therefore, it is important for USOs to bring in people with commercial experience early to steer the venture in the right direction.

Entrepreneurial commitment can be seen as the acts that bind the venture champion to a certain course of events. To fully commit to the business is often hard for academics as it goes against the conventions of the academic world. Furthermore, an imprecise opportunity framing in the previous phase can lead to decision uncertainty that discourages commitment. Lastly, academic venture champions are commonly reluctant to delegate responsibilities and give up control of business related aspects. This causes the venture to move forward too slowly, and can also lead to credibility problems.

In the **pre-organization** phase a first implementation of the strategic plan can be made. As initial funding and time is limited, having the right priorities at this stage is crucial to minimize waste.

To move from the pre-organization phase the academic entrepreneur faces a **credibility threshold**. When looking to access and acquire relevant resources the credibility of the USO is of great importance. Too close ties with the university can lead to hesitation from customers and investors as the venture still lacks a corporate identity of its own.

In the **re-orientation** phase the USO makes a first attempt at generating returns and offerings something of concrete value to customers.

In order to achieve **sustainable returns**, an ability to quickly and efficiently re-configure assets is required. As the company starts to deliver to customers, conditions change fast and learning is rapid.

If finally reaching the **sustainable returns phase**, the USO has resolved many of its early uncertainties. It is highly market driven with a clear business model and a strong focus on winning orders and shipping products.

The three types of researchers identified by Olofsson et al. are mainly connected to the second threshold, entrepreneurial commitment. The types are:

1. The researcher who remains at the university, choosing to let others handle the commercialization process.
2. The researcher who remains at the university but also takes part in the USO.
3. The researcher who leaves the university to take on the USO full-time.

All three types might act in similar ways in an early phase of the commercialization effort. The main difference is the nature of the entrepreneurial commitment. While it is very clear among the third type it might take other, less clear, forms for the other two. (Olofsson C., 2008) claims that there is not necessarily less likely for a USO to succeed if initiated by a type 1 or 2 researcher, but they need to find a way to make the commitment without leaving their university post. Such a commitment could for example take the form of handing over the control of the company to another entrepreneur.

2.5 Remarks on the theory

Three main theories are presented above that will be used to direct and analyze this case study. They are not viewed as encompassing every aspect of that upcoming analysis, but to provide a framework that can be used together with established concepts regarding value creation and market drivers that have not been deemed complex enough to warrant a detailed review in this section.

3 Methodology

In this section the methodology behind the study is outlined. It also includes the rationale behind the choices. The impact of these choices is discussed more thoroughly in the “Discussion” section.

3.1 Framework

Steve Blank, a former serial entrepreneur and author of “The Startup Owner’s Manual” turned professor at Stanford, defines a start-up as “a temporary organization searching for a repeatable and scalable business model”, which is the definition used in this paper. As many other experts Blank advises start-ups to retain an open mind during this search, or research, regarding which application will be the most profitable for their technology. A coherence protocol might naively be expected to have a relatively narrow application space but, as will be shown, this is far from true. Mapping and segmenting the market as well as creating metrics to evaluate the different segments is far from trivial and is the main contribution this report provides to VIPS. The methodology was chosen for this purpose and this section ends with a discussion concerning research strategies for evaluating potential markets for a new invention.

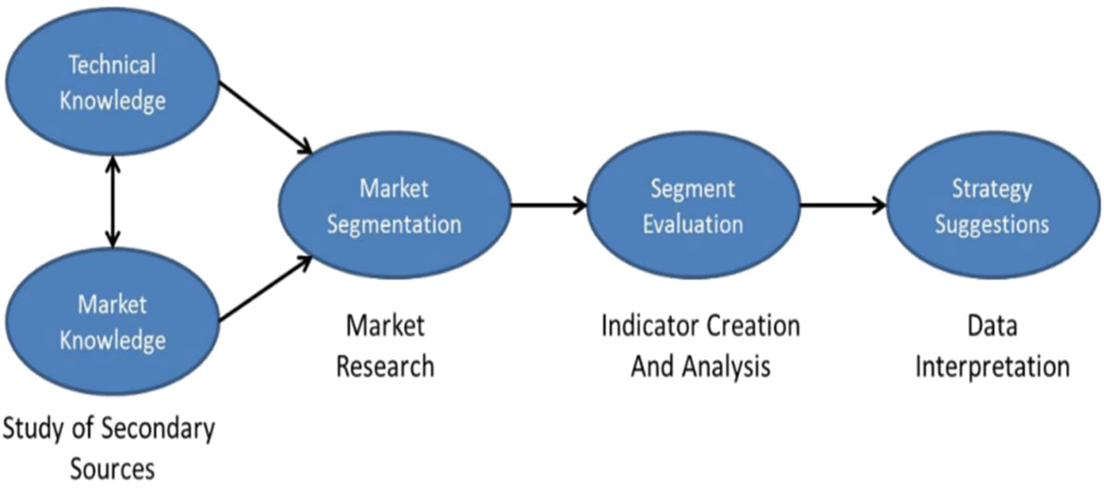

Figure 6. The main phases of the project. The purposes are presented in the bubbles and the work done during the phases is presented underneath.

The case study was divided into four phases, the first of which consisted of a techno-economic analysis of the VIPS technology along with competing and complementary technology, using mainly secondary sources. During this phase several application ideas were generated and a broad research of the markets where these might be used was conducted. The next phase consisted of market research. The most important goals were to find a basis for segmentation of the market as well as develop an understanding of which facts would be most informative of the potential to enter these segments. This was done in a process of continually reformulating the questions, redefining the value proposition and narrowing the scope of the market when the potential of a market segment became discredited. The third phase was a market evaluation and consisted of creating and applying indicators for segment evaluation, based on the facts found during the previous phase. During the fourth phase these indicators were used to give strategy suggestions for the future development of VIPS. These four phases and the work done during them are outlined in Figure 6. In addition to these phases the entrepreneurship process within VIPS was studied and related to relevant academic research in order to provide better and more comprehensive strategy suggestions.

3.2 Study of Secondary Sources

This phase consisted of getting a general understanding of VIPS as well as the markets in which an application of VIPS could be profitable. This was done by iterating between studying the technology on one hand and potential customers and markets on the other.

Initially a broad study of the basic structure of processors, memory storage and cache coherence was conducted. The goal was to get a clear overview of the topic to better be able to understand the technical environment for which VIPS was created. For the purpose of understanding VIPS the sources used were the two published articles by Kaxiras and Ros as well as the first patent application and conference presentations. Using these it was possible to identify which implementations were at all feasible and where the biggest technical benefits seemed possible. Competing protocols were also identified and studied through reference manuals and academic publications.

For a first view of the market, consultant reports and industry websites were examined. A group of potential customers were identified and their current product portfolios reviewed. Here the most important aspects were product compatibility with VIPS and potential benefits. With a first understanding of the technology, the markets and the customers it was time to move forward and find answers to the questions that arose.

3.3 Market Research

The market research phase started with a focus on the applications envisioned by the inventors. The original goal was to identify customers for an implementation in CPUs, with the mobile market suggested as the most probable fit. Once these customers were found a quantification of their benefit was to be assessed and a business plan suggested. Soon data was found which contradicted the initial guesses and a much broader search was initiated with the purpose of finding the most suitable application for VIPS.

The market research was originally supposed to be an analysis of the potential customers, but the unit of analysis was switched from companies to applications. The main reason for this switch was the discovery that the potential customers have very wide product portfolios and the metrics they are using to evaluate technology is not company specific but rather application specific. This is described by (Cortez R., 2020) as a technology based conceptualization of a market, as opposed to a supply based or demand based conceptualization, and is an alternative that is suggested in the B2B market segmentation literature when markets for new technology are being evaluated.

The main goals of the market research were to generate a market segmentation and gather the data needed to create indicators that were well suited for measuring the potential for VIPS in these segments. Another important focus was finding information to evaluate the application segments based on the found indicators.

For the purpose stated above unstructured qualitative interviews, as defined by (Bryman A., 2007), was chosen as a main method. The argument for qualitative interviews was that any hypothesis about which drivers existed would be crude and most likely wrong. By having qualitative interviews where the interviewees were allowed to freely discuss the rationale of their market was judged to give the best chance of uncovering the important benefits and challenges of VIPS. The reasons for not structuring the research were that which questions were most informative was not known at the outset and that interviewees within different segments were likely to have very different drivers. Finding the right questions was very important and far from trivial, and therefore the requirement to ask the same questions to all interviewees would have been counterproductive.

The interviewees wanted were mainly potential customers and anyone further down in their value chain, but also third party developers. Also people with a relevant understanding of important technical aspects, industry knowledge or experience in similar commercialization projects were contacted. The selection process was held rather open, but there were some customers identified in the previous phase that were considered more important. Also, a few user groups were identified as especially important and representatives were selected. One example of this was programmers of graphic cards who were assumed to be greatly helped in their daily work by buying coherent processors enabled by VIPS. The subject selection and interview questions were somewhat restricted by an unwillingness from the researchers to have us present VIPS to potential customers but many such interviews were conducted even if the interviews were required to be somewhat imprecise.

Far fewer entrepreneurial companies in the relevant sector were interviewed. During the DATE 2013 conference in Grenoble a university spin out from Stockholm named ELSIP20 was found and a contact was established. ELSIP's product is also in the field of computer architecture and is closely related to VIPS, but they have come further in their development, having created a first hardware prototype. Given this they could be a valuable partner and give advice on the future development of VIPS. Further contact with ELSIP has been had in Sweden but no meeting has been had yet. It seems reasonable to follow up this contact as well as establish more in the future for a better understanding of the sales process in this market. For a better understanding of the entrepreneurship process in VIPS the more leading inventor, Stefanos Kaxiras, and Mateo Santurio of UU Projekt were interviewed.

Interview subjects were approached in a variety of ways. When there was an established contact from the networks of the participants in the project these contacts were used. Where no such contacts existed the companies or individuals were contacted directly. Many subjects were also found at the DATE conference in Grenoble, which is a five-day conference in the

French Alps dedicated to design, automation and test of processors. In total, 11 such interviews were held. A detailed list of subjects and the reason for interviewing these are found in Appendix A.

A secondary source of information came from the presentations at DATE, where we mainly focused on presentations by industry executives. By watching these presentations and asking relevant questions the current and future challenges of these companies were better understood as well as their marketing strategies.

The collected data was used to create a market segmentation. The purpose of the market segmentation was to create a basis for choosing strategies for marketing, sales and development. We relied on 3 principles in the segmentation:

1. A given market segment should have similar needs, at least as far as it relates to the technology or product being sold.
2. The research and development strategy required for a given market segment should be uniform for all of the segment.
3. A given market segment should be sufficiently large that the start-up could be self-sustaining when successfully selling to this segment.

The focus on the needs of the customer is standard in the B2B market segmentation literature, even when the market is conceptualized as an application space of a technology, and is also advised in the start-up literature. Since the goal is to achieve a “scalable and repeatable business model”, as Blank describes the goal of a start-up, the segment needs to be targetable through the creation of such a model. One may view this as the requirement “the segment should be targetable through a single marketing strategy”

Since research and development is expensive and limited by the competency at hand it is important to choose the right strategy. Having multiple different technical demands from the potential customers within a single segment means that a single research and development strategy is impossible. One may view this as the requirement that “the segment should be targetable through a single R&D strategy”.

In order for the start-up to create a “scalable and repeatable business model” within a segment it should preferably be large enough to support the company. It does not need to be large enough for the future growth the founders hope for since the company can leverage the sales in one segment to break into others as suggested by Moore in “The D-day analogy”. It should however be large enough to support the company as it restructures itself to target additional segments.

3.4 Indicator Creation and Analysis

With the information acquired from the previous phase the number of interesting markets could be narrowed to four, mainly due to compatibility problems with existing technology or a lack of fit between the technological features of VIPS and the market drivers. After this narrowing the next step was to create a framework for evaluating each of the chosen market segments against the others for the purpose of advising VIPS on their selection.

To create such a framework for market segment evaluation, an attractiveness metric with four attractiveness indicators was formulated. These indicators were barriers to entry, the value created for a first customer, the value that could be captured and finally the potential for long term profits after the first sale. The choice of indicators was heavily influenced by the information gathered by this stage and are meant to reflect the potential problems and profits expected when choosing a specific segment. These indicators are defined and justified in chapter 6.4.

During this phase the results were also triangulated using quantitative secondary sources as well as theory regarding the general situation for a high tech start-up, following the suggestions of (Golafshani N., 2003). Also secondary sources were investigated in order to provide additional information for the indicator-based segment analysis.

Much of this work was focused on the specific players of the market for graphic cards and general market drivers of the embedded market as these quickly could be identified as more interesting than the others. The main sources used were company websites and industry analyst statements for the GPUs and industry reports for the embedded market.

3.5 Data Interpretation

Using the data acquired in previous phases as well as secondary sources a strategy was to be suggested. The strategy was to include a first market segment suggestion, a second market segment suggestion, general suggestions on R&D strategy designed to enter each market segment, marketing & sales strategies for each segment and some suggestions regarding how to continue building the company based on relevant theory regarding university spin offs.

Since this process relied heavily on the data collected it is described in chapter 7, after the findings, market segmentation and attractiveness indicator values have been established.

4 Technical Background

This chapter explains the basics of computer architecture and cache coherence. It also outlines the principles of the VIPS protocol as described in the patent applications. Finally, it summarizes the key features of VIPS compared to standard protocols.

4.1 Computer Architecture, MPUs and Chips

Computer architecture deals with the relations and parts of a computer system. An integral component of such a system is the microprocessor unit (**MPU**) and its uses of computer memory. The MPU is the part of a computer that reads and modifies data to do computations, while the memory is where such data is stored. To control the data flow **instructions** are used, which determine how and in what order computations should be made. A series of instructions designed to be processed one after the other is called a **thread**. Several threads handling different aspects of the same task together form a program.

What kind of instructions can be sent is determined by the used instruction set, meaning the totality of instructions that can be used to specify the work of the MPU. There are two main paradigms for how instruction sets are constructed today - **RISC** (Reduced Instruction Set Computer) and **CISC** (Complex Instruction Set Computer). RISC contains fewer but simpler instructions while CISC is more specific but also requires more bandwidth. The former is dominating in most mobile applications and integrated systems not normally perceived as “computers”, while CISC is used in most conventional computers. Examples of RISC-architectures include the ARM architecture while CISC usage is dominated by the x86 architecture pioneered by Intel.

When the MPU is integrated together with all components required to perform the processing tasks it forms a **microchip**. In modern desktop and laptop computers, this component is called the central processing unit, **CPU**. As increased integration reduces size and thus costs of materials, many modern systems include not only the CPU, but all parts of the entire computer system on a single chip, a so called System-on-Chip (**SoC**).

4.2 Multicore Processors and their Memory Hierarchy

The main parts of a MPU are the processor **cores**. The cores are the computational units of the processor, the rest being wiring and circuitry needed to supply the core with data to work with. The last years have seen a great rise of multicore processors, consisting of several cores within the same chip. Each core has an individual **cache**, which is a temporary memory storage for data currently used for computations. In many cases, these data are copies of data from the main, shared, memory (such as the RAM in a computer). Also, each processor unit has a shared cache to which all cores have access. This cache, usually referred to as the *Last Level Cache* (**LLC**), is larger than the individual caches. However, accessing it takes longer time than accessing the individual caches. When the required data is not found in a particular cache, it is referred to as a “cache miss”. This structure is shown in Figure 7.

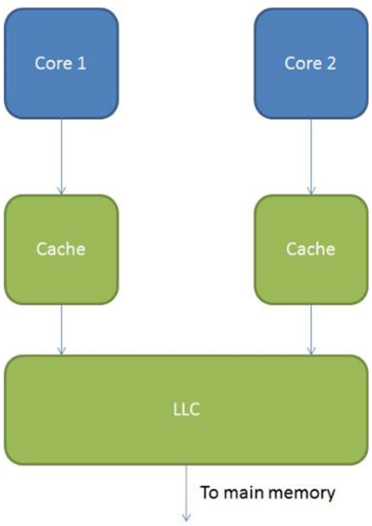

Figure 7. Conceptual representation of a dual-core processor with two-level cache. Each core has one private cache while they share the bigger Last Level Cache.

Thus, the design of the memory structure is a trade-off between reducing the number of cache misses (by increasing cache size) and reducing access time when a miss does occur.

To get an understanding of why this kind of memory hierarchy is used, consider the following analogy: Reading from the local cache is like grabbing a piece of paper from your desk, reading from the LLC is like picking up a book from a nearby shelf and reading something from main memory is like taking a 4-minute walk down the corridor to borrow a book from a colleague. We will not discuss it any further, but waiting for a hard drive to read is like leaving the building to roam the earth for a year. (Duarte G., 2008)

4.3 Coherence and Data Races

In order to construct a multicore system, or rather to construct one that can run efficient multi-threaded programs, you need cache coherence. Modern computer programs often run in parallel, meaning that the tasks are split into different threads running at the same time. These threads can access the same data in the shared memory and when they are running in different cores they need to make sure that they both use the correct version of the data. A common analogy is two ATM-machines and two persons with two debit cards connected to the same bank account, containing 100 SEK. If both people simultaneously inserts their cards in both machines and tries to withdraw the 100 SEK, only one of them should be allowed to do so. But if both machines check the balance at the bank at the exact same time, both will see that the account contains 100 SEK and if no other controls are made both will give out the money. The ATMs need to be **coherent**, meaning that transactions should not give different results depending on the exact timing of the events.

If two cores in a multicore system both want to read some data, they both need to copy it to their local cache. If one core then modifies the data and the other one still wants to read it, the system must implement a behavior that allows the new value to be copied into the second core to prevent it from reading old data. When two threads try to read and write the same data at the same time this leaves the order of the operations, and thereby the outcome, to chance. This is called a **data race** and is generally considered bad practice by programmers. Data races can go undetected for a long time if, for example, the order of operations always are the same and in that case they are referred to as “silent”, meaning that they never cause any errors in practice. However, such data races might cause problems when the code is ported to a different architecture.

4.4 Directory versus Snooping

There are several ways to keep local caches coherent. Two ways it can be implemented in hardware are either using a snooping protocol or by the use of a directory. Snooping is a process in which each individual cache monitors the traffic on a shared communications bus (a communications line between the circuits), “listening” for accesses to address lines or memory locations they have stored in their cache. If two different cores both have a copy of a certain data and one of the cores wants to write it, a notification of this is sent out on the bus. As each core monitors the bus, each one will check if they have the data stored in their cache and mark it as invalid (invalidate it) if there is a match, see Figure 8.

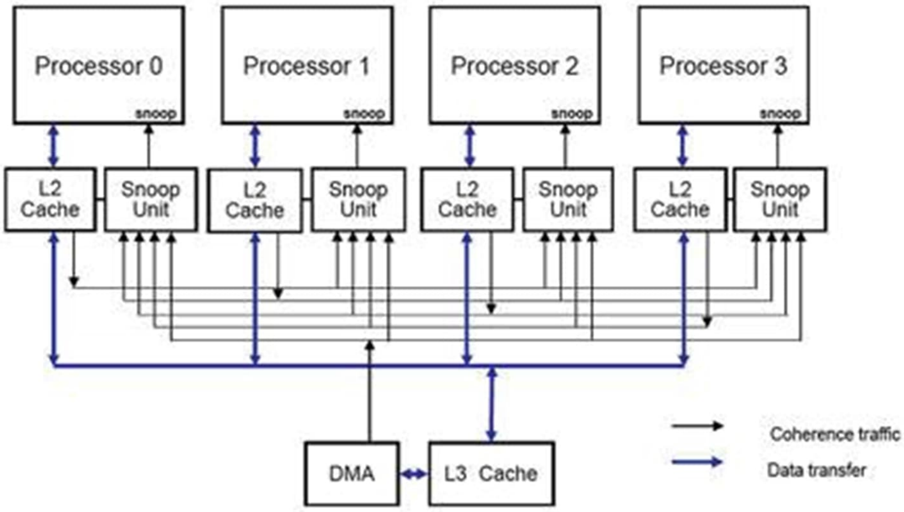

Figure 8. Illustration of a snooping protocol. Apart from the data transfers, several other connections are needed to inform each core of actions initiated by the others. (Orozco R., 2010)

Snooping is a very easy way to ensure coherence and is widely used in processors with only a few cores. However, as all notifications are sent out on a single bus heavy traffic loads become a problem for larger many-core processors. To relieve this problem, a directory-based system can be used instead. Unlike a snooping protocol, only those cores that are affected by a change of data are notified. A specific hardware controller called the directory keeps track of what data are stored in which caches to allow point-to-point notifications. If a core wants to write, a notification of this is sent to the directory. The directory then checks where the affected data is stored and sends a notification of invalidation to those caches that are concerned. The use of directories significantly reduces traffic for many-core processors as only those caches involved are notified of changes. However, the introduction of a directory requires more space as it has to index all data and keep track of their respective states. (Orozco R., 2010).

4.5 The MESI protocol

MESI is one of the most fundamental coherence protocols used today. In its original form it dates back to 1984 but it was first used for personal computers in the Intel Pentium architecture in 1993 (Intel, 1997). The fact that the protocol is old and very widely used means that it is in many architectures a fundamental piece in maintaining **legacy** compatibility, i.e. the ability to run code and applications originally designed for one generation of processors on newer versions of the same architecture.

MESI supports write-back of cache data in addition to the more fundamental write-through. A Write-through policy means that any data that is modified in the cache is immediately sent to the external memory as well; simplifying coherence but making the system perform lots of time-consuming writes. It is far more efficient to use a write-back policy in which the write to memory is delayed until it has to be performed for some reason. MESI enables this by tagging each data entry with two extra bits, identifying the data as Modified, Exclusive, Shared or Invalid.

Data is originally brought in from the memory by one core and set to state Exclusive. If a second core wants to read the same data it receives a copy from the first core and both change the state to Shared. If one of the cores then wants to write the data it broadcasts an invalidation command that makes every other core containing the data change its state to Invalid while the broadcasting core changes the state to Modified. Next time the core sees a request for the data it writes the changes back to the main memory and resets the state to Shared. (See Figure 9 for a schematic view of the MESI states) There are several optimizations possible both using the basic four states and by introducing a fifth or even more states. The performance can also be improved by replacing the “headless” snooping with a directory or other type of controller, at the cost of increased complexity.

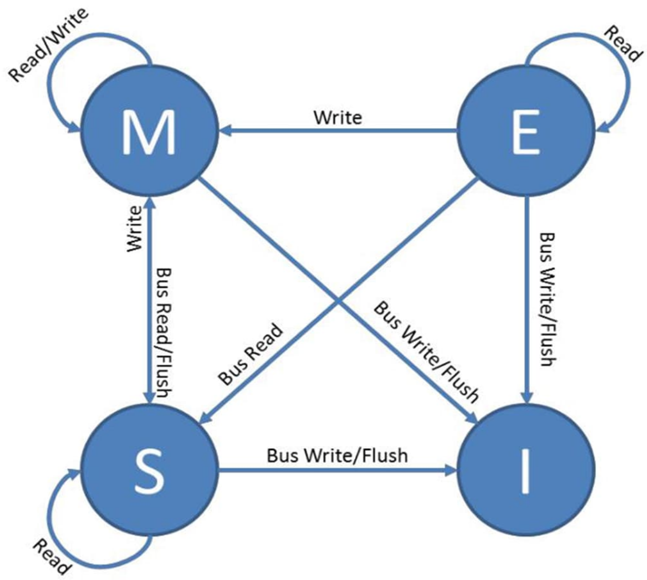

Figure 9. The states of the MESI protocol and the actions that cause transitions between the states.

4.6 Problems with old coherence protocols

Older coherence protocols, such as MESI and its derivatives, perform very well in systems with few cores and very large differences in latency between cache and main memory. Therefore it has been very successful during the last twenty years. Today, however, the modern computer is fundamentally different. Even a relatively simple device such as a smartphone usually contains at least two main processor cores (CPUs) and three or more graphics accelerator cores (**GPUs**). These are connected to extremely fast LLC units that are large enough to more or less eliminate the need for recurring data reads from the main memory. MESI grows increasingly inefficient with the number of cores since it relies on broadcasts and snooping while at the same time fails to utilize the faster LLC in modern systems. The broadcasts also require that every core use the same (global) addresses to identify the same data, making it impossible to use so-called virtual memory addressing. The major differences between CPUs and GPUs also make it difficult to incorporate them within the same coherence protocol, resulting in separate memory for the two systems.

4.7 The VIPS protocol

VIPS stands for Valid/Invalid, Private/Shared and refers to the two different state variables needed (Kaxiras S., 2012). The VIPS protocol aims to simplify coherence by reducing the number of states, as well as the overhead needed to carry out instructions. As an invention VIPS is separated into distinct stages, including VIPS, VIPS-SF, VIPS-M and finally VIPS-V. VIPS describes the basic idea behind the invention and presents a protocol that would be perfectly compatible with older systems. VIPS-SF describes improvements to VIPS culminating in VIPS-M as the most efficient implementation of the protocol, but with some risk of legacy incompatibility. VIPS-V presents a way that VIPS-M could be utilized to integrate systems outside the processor itself.

Apart from the two state variables, Valid/Invalid, Private/Shared, a third, transient dirty, also exists but is not visible outside the core and its cache. VIPS uses different write policies for shared and private data, states that are set outside the cores and usually not changed. To enforce coherence a directory is needed to keep track of cores writing shared data. This guarantees completely transparent behavior and no changes in existing code are necessary if the classification of private and shared are implemented in hardware. Data-races are allowed and handled similar to MESI. Since this original form of the invention is not considered to be commercially interesting it will not be described further.

4.7.1 VIPS-M

The completed form of the invention is known as VIPS-M. This protocol is completely free from directories or snooping, which makes it more efficient than MESI or similar protocols. Coherence is enforced using self-invalidations at synchronization points, which has the effect that data races are not allowed (or rather, data races will usually yield different results compared to when running on MESI-type coherence). As in VIPS, private data uses a pure write-back policy, only writing modified data to the LLC when it has to be evicted from the local cache due to limited free memory. Shared data basically uses the same policy, but data are also written back when the core encounters a synchronization event in the code. In this case the local copy is invalidated as well.

One problem with this approach is the granularity of the data. The nomenclature of memory handling is as follows: The base unit is the **word**, which is what we usually call one variable in programming. Several words make up one **line** (or block). A line is data that is physically placed adjacent to each other, but there might be no other relation between the words. Several lines make up one **page**. The exact sizes in bits of the word, line and page differ between computer architectures but the communication between the memory, LLC and private cache, as well as the classification of data, is usually made at line granularity. The fact that the memory system exchanges lines of data when the cores operate on specific words might lead to false sharing, meaning that two cores use two different words in the same line. If both cores were to write back the entire line to the LLC it would look like a data race, even though the program code contains no such race. This is solved in VIPS-M by tracking the modified data at word level within the local cache and implementing the ability for it to write back only the modified words to the LLC. This means that modified words are merged into the lines at the LLC, which is what the M in VIPS-M stands for. This is illustrated in Figure 10.

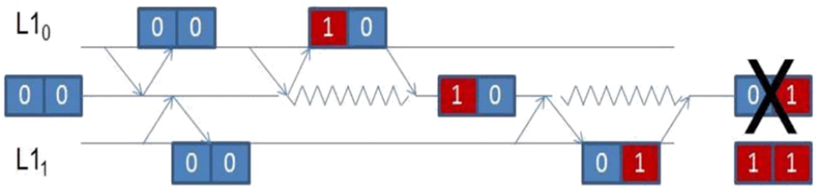

Figure 10. Two L1-caches (cores) writing different words (the colored numbers) on the same line to the LLC (middle). This might cause the second core to overwrite the changes done by the first. (Kaxiras & Ros, 2013b)

4.7.2 Classification of private and shared data

In both VIPS and VIPS-M, we assume data to be classified into private or shared. This can be done in several ways. The simplest way, from a protocol perspective, is that the applications themselves (or rather the operating system running the applications) define data as private or shared when the data is originally written. The main problem with this approach is that the code must be modified if someone wants to run existing applications on a VIPS-system. There might also be efficiency losses since operating systems often classify data at page level, leading to lots of data falsely classified as shared. A hardware implementation would take away some of the simplicity of VIPS-M, but might be necessary. Such a system could work in the following way: A directory-like structure at the LLC keeps track of which core accesses which data. To begin with, all data is classified as private but when a second core requests to read a specific line that line is set to shared. Before any data is sent to the requesting core, the LLC sends an instruction to the core that has previously accessed the data. That core sets its local copy to state shared, and if it has been modified it has to be written back to the LLC before it can be sent to the second core. This process is illustrated in Figure 11. (Kaxiras S., 2012)

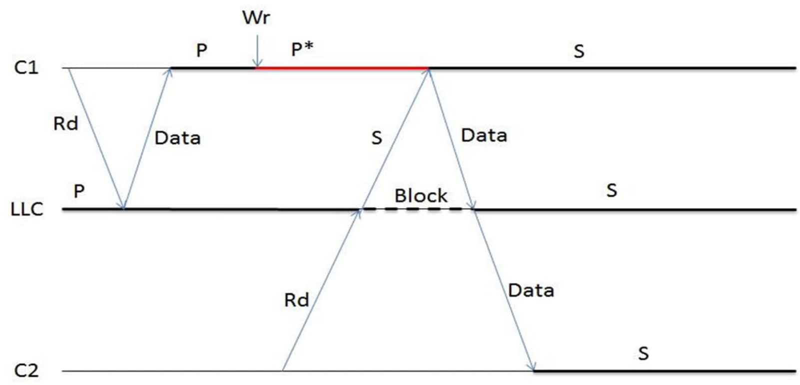

Figure 11. A schematic view of data transitioning from private to shared. The first core (C1) starts by reading the data and then writes a new value. When the second core (C2) then wants to read the data it must first be updated in the LLC.

4.7.3 VIPS-V

A second invention based on VIPS is the idea referred to as VIPS-V (S. Kaxiras, 2013), V for virtualization. This invention uses the properties of a system implementing VIPS-M to solve another problem, that of virtual memory in caches. **Virtual memory** is a system where memory is accessed using addresses that do not represent any physical location in the memory. Regarding processor cores and caches, virtual memory is mostly used to give programs the ability to reference all the memory space it needs without having to worry about where in the memory structure this is actually stored. This simplifies the programs and makes it easy for the operating system to optimize memory usage by moving seldom-used data to the hard drive (the practice that is most usually implied by the term “virtual memory”). However, though it has several advantages to let the program code use virtual memory, it will make cache coherence harder since the cores would not know which virtual address in another cache corresponds to which post in the private one. To solve this, addresses are usually translated from virtual to physical ones directly outside the core before the cache is accessed. The translation is done by a separate unit called a **TLB** (translation lookaside buffer), as shown in Figure 12.

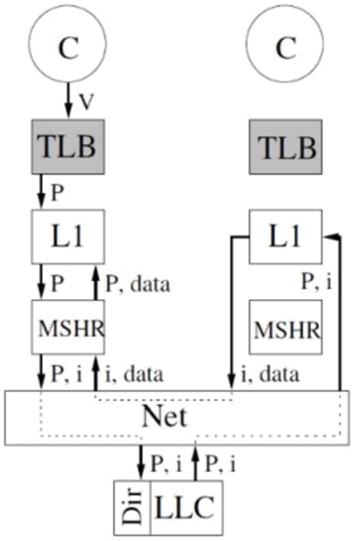

Figure 12. Cache coherence in the MESI protocol. A TLB-unit translates the addresses before the private cache (L1). Here the core to the left is trying to fetch data which the directory knows is present in the core to the right. (Kaxiras & Ros, 2013a)

If the VIPS-M protocol is used, no communication between the cores is needed. This allows for something that is very complicated using other protocols: moving the translation point further up in the hierarchy, as seen in Figure 13. This saves time and energy since it is not needed to make a translation for every operation.

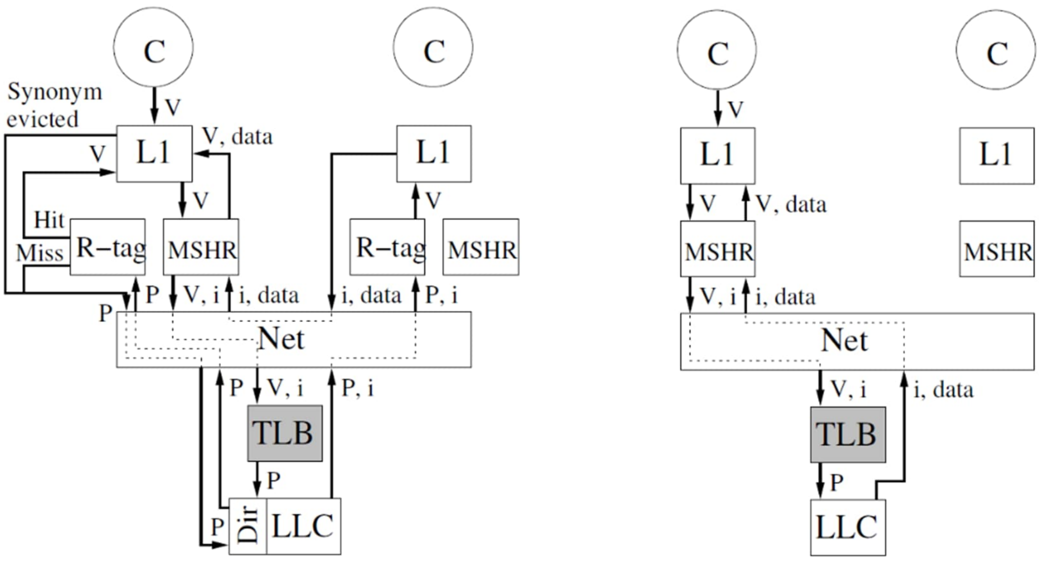

Figure 13. Address translation at the LLC for two different protocols: a very complex MESI on the left and VIPS-V on the right. (Kaxiras & Ros, 2013a)

This is especially interesting in systems where it is hard to fit a TLB to every core, such as systems with large numbers of very simple cores. In many such cases virtual memory is not used at all today (Wainwright I., 2013).

4.8 Features of VIPS

Compared to classic coherence protocols, such as MESI, VIPS has the following advantages and disadvantages:

- **Performance**. In simulations made of a 16-core CPU, VIPS-V performed on average 5.4% better than MESI measured in execution time of standardized benchmarks.

- **Power efficiency**. A model of the same 16-core system show that the memory system should consume 20% less power using VIPS-V instead of MESI. It should be noted that this is only for the memory system, not for the cores or other functions. How much this would mean for the total power consumption will vary for different designs, but it could be as much as 14% total power reduction for the complete processor. (Wainwright I., 2013)

- **Chip area**. By removing the directory and combining the TLBs in one place, VIPS-V would reduce the area required on the chip. In the example above, this would mean a total reduction of about 0.75 mm2 or 2.6% of the total area for the memory system.

These three measurements, often collectively referred to as Performance, Power & Area (**PPA**), are illustrated in Figure 14.

- **Performance**. In simulations made of a 16-core CPU, VIPS-V performed on average 5.4% better than MESI measured in execution time of standardized benchmarks.
- **Simplicity**. As mentioned, VIPS is far simpler than MESI or other coherence protocols. This is mostly an enabling feature for all the rest, but for some implementations simplicity, including reduction of the number of states, might bring additional benefits.
- **Virtual caches**. VIPS-V is one of the first attempts to efficiently utilize virtual caches in a coherent system. This has several implications beyond improving PPA, such as the ability to enable coherence in systems that have previously not been possible due to the complexity of using older protocols and physical addressing.

Data Race Free. As discussed earlier, data races are not allowed in VIPS. This results in a different behavior than MESI and old programs might not work reliably. Some processor architectures already impose these limitations for different reasons, which would remove the problems with legacy compatibility.

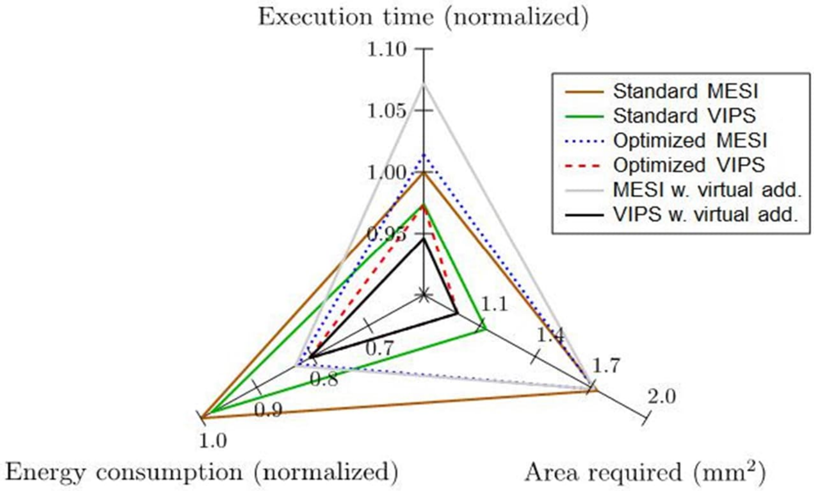

Figure 14. PPA for different coherence protocols on a 16-core CPU. (Kaxiras & Ros, 2013a)

5 Entrepreneurial Background

VIPS is an invention by the two scientists Stefanos Kaxiras and Alberto Ros. Professor Kaxiras has more than 20 years of experience in the field and has worked in the industry at Bell Labs for five years. He is a professor at Uppsala University since 2010. Dr. Ros is currently working at University of Murcia, Spain, but previously held a post-doc position in Uppsala (Universidad de Murcia 2013). Kaxiras, who had read about his work, recommended him for that job. Although they did not initially work within the same project, they started examining ways to combine their research, which led to the creation of the VIPS protocol.

5.1 HEAP

VIPS was originally developed within the HEAP project, which is an EU-funded research project for future multicore technologies in collaboration between several universities and companies (HEAP 2013). The industrial partners of the project have a non-exclusive right to license all inventions made within the project, which includes VIPS. So far, the only party to show an interest in this is STMicroelectronics. The first two papers on VIPS were published as parts of this project in September 2012.

5.2 Patents and start of commercialization

Early on the scientists decided that they would like to develop VIPS further outside of the scope of HEAP and try to commercialize it (S. Kaxiras, 2013c). Therefore they contacted UU Projekt AB, which is a subsidiary of Uppsala universitets utveckling AB (UUAB) - the holding company for the university's investments in academic spinout companies. UU Projekt has financed the continuing development of a possible business centered on the VIPS technology since early 2012. This includes the work done by Forskarpatent i Uppsala AB who have helped filing the patents for the project. No patent application was filed before the first paper was submitted, making it impossible to obtain a patent anywhere else but in the USA where patent law gave a one-year grace period from the first submission. Since North America is one of the largest markets for semiconductor products, this limitation was not considered to be important. In total, three provisional patent applications were filed during spring 2012. The first of these was converted into a proper patent application in February 2013. The work has since continued by attempting to form an advisory board for the project, consisting of people with experience from the industry.

Another thing that was done through the cooperation with UU Projekt was a market analysis performed by the consulting company TTO A/S (P. N. Jørgensen, 2012). This report made preliminary evaluations about potential market size and deal terms. It did not discuss the technological feasibility of VIPS or look closer at different market segments and their drivers. For that reason it has not been used as a basis for this report.

STMicroelectronics, as a partner of the HEAP project, have requested a joint evaluation project to see if VIPS could be used in their future products. A PhD-student is currently investigating how to do such an evaluation, which will be the basis for an offer to the company.

5.3 Visions of the Inventors

The scientists initially envisioned a process where the invention could be licensed to one of the big companies in the business, e.g. ARM, as an incremental improvement to their products. Later on they also began investigating the possibilities of using the technology to enable new kinds of products. Meetings with representatives from several companies have been held, but apart from STMicroelectronics no further collaborations have been initiated.

Kaxiras states that his primary goal with the project is to get the technology used in consumer products. He has earlier experience with companies using patents simply to block others from exploiting new inventions and he does not want VIPS to experience the same fate. He is at the same time quite confident that this can be achieved by building a revenue-generating company. None of the inventors feel the need, or want, to leave the university. They want to remain researchers and Kaxiras has stated that he sees this project taking up about half of his time in the upcoming years.

The third paper on VIPS was accepted for ISCA 2013 (International Symposium on Computer Architecture) (HEAP, 2013a), which is one of the most prestigious conferences in the field. This paper focused on the possibility of using VIPS to enable new solutions and was not part of the HEAP agreement. The next phase of the research will focus on showing how VIPS would behave when the system is scaled up to connect a multitude of cores. The project has also been granted funding from VINNOVA which cover continued development and creation of a proper business plan over a two-year period. (Kaxiras, 2013a). In Olssons model presented in chapter 2.4 these steps would bring VIPS from the research phase to the opportunity framing phase through an opportunity recognition, that is the match between a market need and a satisfactory solution.

6 Findings

In this section, the findings of the study are summarized. This includes an overview of the market's structure and commercial benefits that VIPS could bring as well as an analysis of the applications that VIPS could be implemented in. From this data a market segmentation is created and a number of indicators are defined.

6.1 The Semiconductor Industry

The exact market and the potential customers of VIPS will depend on what applications the project finally chooses to target. However, all possible applications would still be part of the semiconductor industry. This is a broad term for an aggregate of all companies involved in the design and manufacturing of semiconductor devices. For VIPS, mostly companies engaged in the production of microcomponents, i.e. microprocessors and microcontrollers, would be of interest. However, many of the fundamentals and drivers are general for the semiconductor industry as a whole. Also, most major companies are involved in a multitude of branches and a majority of the available market research addresses the entire industry. For these reasons, this report will first explore the semiconductor industry as a whole before targeting certain applications.

6.1.1 Market Overview

A fundamental principle that has defined the industry for over 40 years is known under the name of “Moore’s law”. Discovered by Intel co-founder Gordon Moore in 1965, it states that the number of transistors on integrated circuits will double approximately every two years. This prediction has proved so accurate that many companies now set their goals for future development to keep up with its predicted outcomes (Disco C., 1998). Increasingly, this has put enormous pressure on R&D (research and development) to keep up, with escalating costs as a consequence.

The industry’s rapid innovation has made it a driving force of the information technology revolution. Its role as a technology enabler of electronics hardware makes it a key player for both technological and economic growth. Today it accounts for about $300 billion in sales and is estimated to enable another $1600b in electronics. Including indirect impact on industrial and service industries it contributes to a total of almost $10 trillion in revenue or 10% of world GDP, see Figure 15.

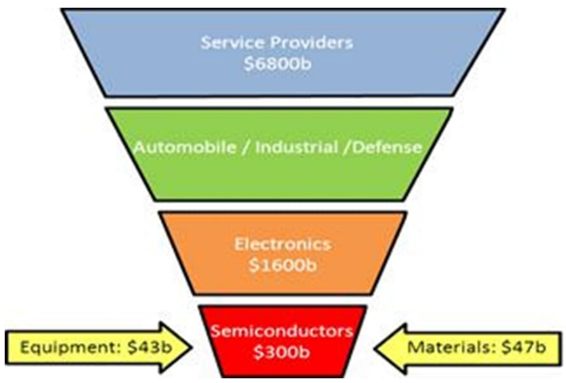

Figure 15. The semiconductor industry is a key driver of economic growth.

The close ties to the electronics industry make the demand for semiconductors heavily influenced by the demand for electronics. Global dissipation of electronics, as well as an increased inclusion of semiconductors in new electronic equipment, has caused the industry to double its revenue over the last ten years. Equally important has been the semiconductor industry's ability to raise it share of the sales of electronics from 10% in the early 90s to 22% in 2010. Part of the reason for this is a shift towards integration of more system IP in chipsets, where chipmakers include both hardware and the necessary software in their products. Also, increased competition and low differentiation have forced Original Equipment Manufacturers (OEMs) to lower prices while semiconductor companies have been able to keep their price level.

While the industry's growth has been sustained over a long time, the main driver of its demand has changed. Historically, the growth of PCs was the primary source while mobile and multimedia devices now have taken over the role as key drivers. In the future, growth in systems for health, energy and security applications are projected to propel demand even further (Millard J., 2012).

6.1.2 Industry Breakdown

While there exist a plethora of different devices and models, five major product categories can be identified and classified. These are discretes, optoelectronics & sensors; analogues; microcomponents; logic and memory. Following is a short description of each category, including examples of specific devices:

Discretes, Optoelectronics & Sensors: This category includes all semiconductor components that are not integrated circuits. Discretes are packaged single transistors like diodes, switches and power transistors. Optoelectronics include displays and laser devices while sensors are all devices that measure physical or chemical properties, e.g. temperature and pressure.

Analogue: Analogue circuits process real world analogue signals like sound and light and represent them as electronic voltage patterns. Examples include amplifiers, voltage regulators and data converters.

Microcomponents: This category includes digital processors like microprocessors (CPUs/MPUs), microcontrollers (MCUs) and Digital Signal Processors (DSPs). Digital processors are binary, using "1" to represent the presence of a chosen property, while "0" represents its absence. As they only deal with digital signals, all real world inputs have to be converted from analogue to digital before they can be processed. Microcomponents are used for computations and control of electronic devices and systems. The most complex and powerful devices are the microprocessors, which can perform a range of functions and typically form the brains of entire electrical systems. Microcontrollers are simpler and commonly application specific devices that are dedicated to specific functions, while DSPs are specialized to process real-time data.

Logic: Includes all non-microcomponent digital logic circuits. Common examples include Application Specific Integrated Circuits (ASICs), Application Specific Standard Products (ASSPs) and Field Programmable Gate Array (FPGAs). ASICs are hardware customized for a certain customer to perform specific tasks, while FPGAs are designed to be programmed (and possibly reprogrammed) by the customer. ASSPs are similar to ASICs but are sold to more than one customer.

Memory: Devices that are used to store data in silicon. Common examples include SRAM and DRAM, as well as flash memory.

Each of the categories makes up a significant share of the total sales in the industry, with logic components having the largest revenue and analogue the least, see Figure 16.

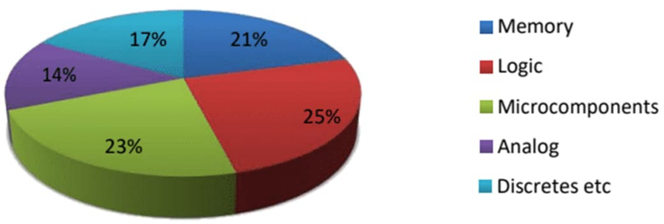

Figure 16. Semiconductor market share by category. (Databeans, 2012)

Logic, microcomponents and memory are all categorized as digital integrated circuits and typically have a more complex design and functionality than analogue and discrete. Another aspect is standardization - the more standardized the product, the more price sensitive it is with low margins and a high reliance on scale. For these products, efficiency in the production process serves as the greatest barrier to entry. Especially in memory, maintaining a high "yield", i.e. a low number of defect products, as well as high utilization rates of manufacturing capabilities are crucial to be competitive. For more specific products such as ASICs, tight customer relationships and flexible and customer driven design capabilities are key. As the needs of customers are more varied in this market, there is more room for smaller and specialized companies and the barriers to entry are smaller. Microcomponents have more general applications than logic but are still not commodity products like memory. Thus, to compete in this industry a number of capabilities are required, including process efficiency, innovative product development and close customer relationships. (Ballhaus W., 2009). The degree of application specificity is represented in Figure 17.

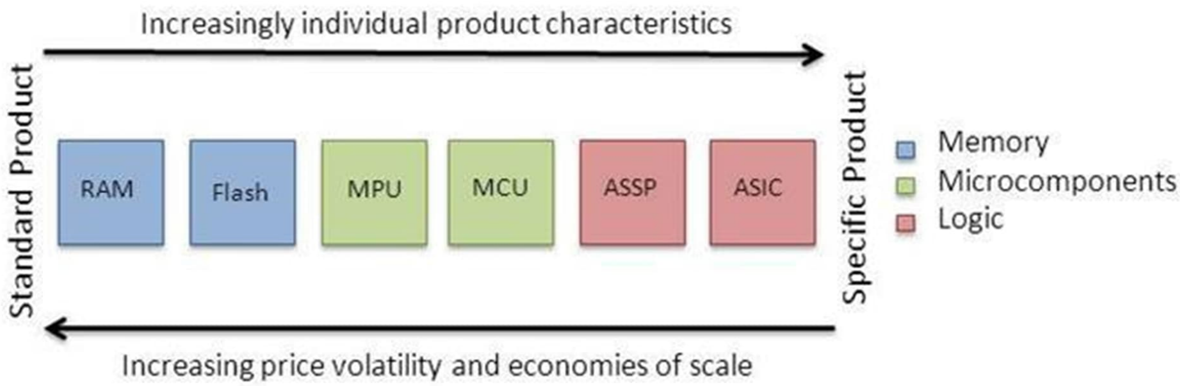

Figure 17. The customization of products differ greatly between applications. For customized products, economies of scale are less important.

6.1.3 The Value Chain

Traditionally, large players with both design and manufacturing capabilities have dominated the semiconductor industry (Naeher U., 2011). These so-called Integrated Device Manufacturers **(IDMs)** operate along the entire value chain in semiconductor manufacturing and typically deal with high volume products. Production facilities require very high levels of investments, leading to economies of scale being essential. This has led to one or a few IDMs dominating each market segment for a long time, e.g. Intel in microprocessors, Samsung in memory and Texas Instruments in analogue (Shaefer R., 2011).

However, added complexity has led to ever increasing investment costs in manufacturing. New production facilities require not only state-of-the-art facilities and equipment, but also heavy R&D to continuously improve the process. Furthermore, depreciation is huge due to the technology quickly becoming obsolete. Thus, even some of the biggest players have found it hard to compete in manufacturing and instead let partnering companies do some or all of the manufacturing.

The above-mentioned complexity has given rise to specialized manufacturing companies, so called **foundries**. These are companies only dealing with production without any product development of their own (Ballhaus W., 2009). By pooling production from several other companies they can operate at a larger scale and thus recoup high investment costs faster.

The emergence of foundries has opened up the playing field for new players. These **fabless** companies contract the manufacturing to foundries and only focus on R&D in design, as well as on sales and marketing of their finished products. Not only do these companies require less capital investments, profit margins are typically higher and earnings more stable (Shaefer R., 2011). Scale, while still important, is not as crucial and therefore there is less of a winner-takes-all dynamic in this part of the industry. As an effect, fabless companies can be highly specialized and compete by dominance in specific applications rather than across applications (Shaefer R., 2011). These advantages have translated into an increasing number of companies adopting this business model, as can be seen in Figure 18.

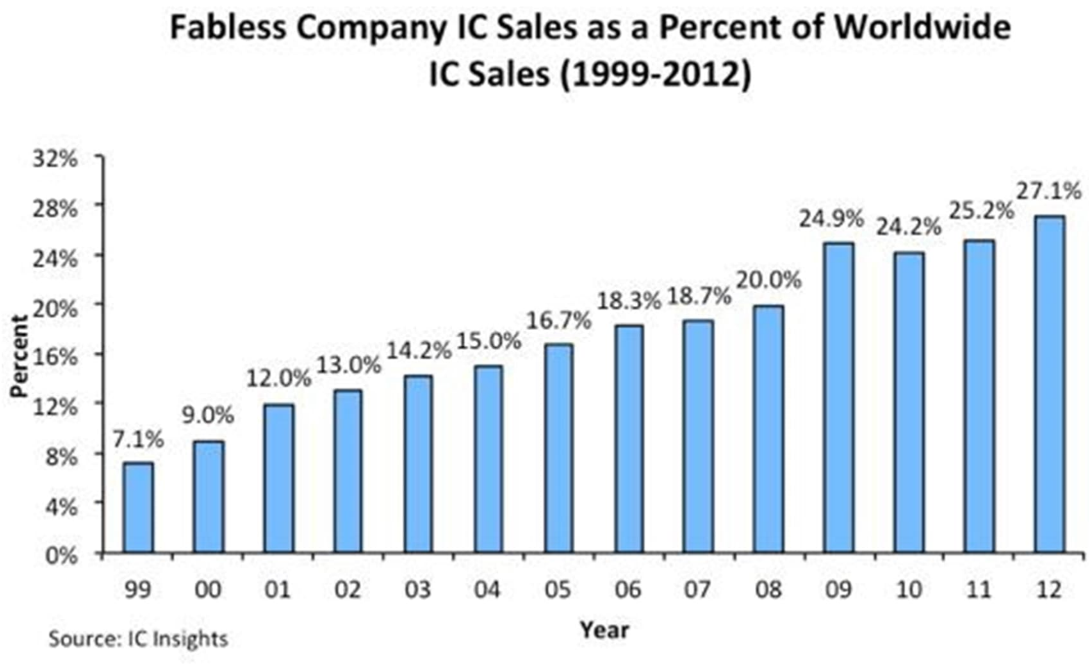

Figure 18. Fabless companies have captured an increasing share of the market over the last 15 years. (Silicon Semiconductor, 2013)

An even leaner organizational structure is the one of the **IP Vendor.** These companies have no sales operations of actual products but deal strictly with the design of modules that are then licensed out to third parties. The IP is often used as a blueprint for other companies to build their customized products upon. An example of this is ARM that have come to dominate the market for cellular processors by licensing out its architecture to fabless designers.

Another corner of the market that has opened up is the **assembly and test** industry. Companies in this sector deal specifically with the packaging and testing of chips from the foundries. Compared to the foundry market, there is less reliance on advanced machinery for automation and more manual work is required. Thus economies of scale are less important and a comparably large number of firms operate in this market, predominantly in low cost Asian countries (Naeher U., 2011).

The emergence of leaner and more specialized companies has restructured the industry. While the production of a chip used to be a linear process by one of the IDMs, a modern chip is increasingly the work of a number of collaborating companies. Consequently, the modern industry is better described as a complex ecosystem with high interdependence, rather than a highly linear and vertically integrated model that for a long time was the standard (see Figure 19) (Shaefer R., 2011).

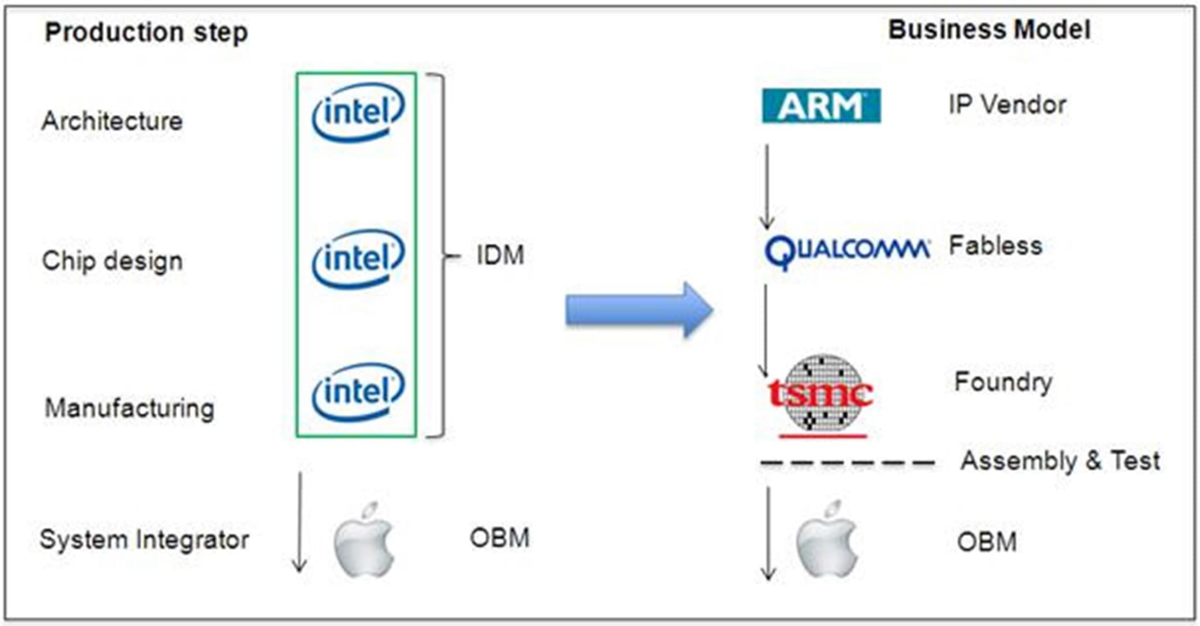

Figure 19. The industry's value chain has become more fragmented over time with fewer pure IDMs active in the market.

The value chain does not stop at hardware though. In many cases, the developers of software are an important player as ultimately hardware is only an enabler to run applications developed by software providers. This is a large reason for the many different chip designs, as different chips have different compatibility and efficiency on different kinds of software. When designers of hardware try to improve the features of the chip, they also have to consider what kind of software will be able to run on it. To justify problems with compatibility or legacy code, a very significant improvement is typically required (Goodacre J., 2013). To what degree a hardware supplier can push new specifications depends to a large degree on how complex the ecosystem surrounding the product is. The larger the ecosystem, and the less control of it the supplier has, the harder it is to push new specifications that change the software dynamics.

6.1.4 The Design Process

While the industry has become more specialized, each field has had to deal with new challenges. To keep up with Moore's law, chipmakers are operating on smaller and smaller scales to cram in more and more transistors. This increases the risk for error and has caused the design costs for new chips to explode. As a result, the number of new chip designs has steadily decreased since the turn of the millennium. A major component of the added costs is constituted by verification costs, which have increased dramatically and continue to rise (see Figure 20). The ever-increasing costs of verification, together with its crucial role for determining a product's time to market, have caused major efforts to simplify the process. Deciding how much functionality that needs to be properly verified is one such ongoing consideration; while verification is a large cost so might shipping an unreliable chip be. Another example of how to reduce verification costs is to include already validated parts from previous generations in a virtual emulation. This has the benefit of speeding up the development of complementing software, which is another major cost in today's designs. As manufacturing has become more and more commoditized, inclusion of software has become a key differentiator in the market. Vendors can no longer just provide individual components but must also develop systems software on which OEMs later can customize their products. As modern hardware, like multicore processors, require a considerable understanding of system integration for effective use the importance of software is likely to continue to increase (Millard J., 2012).

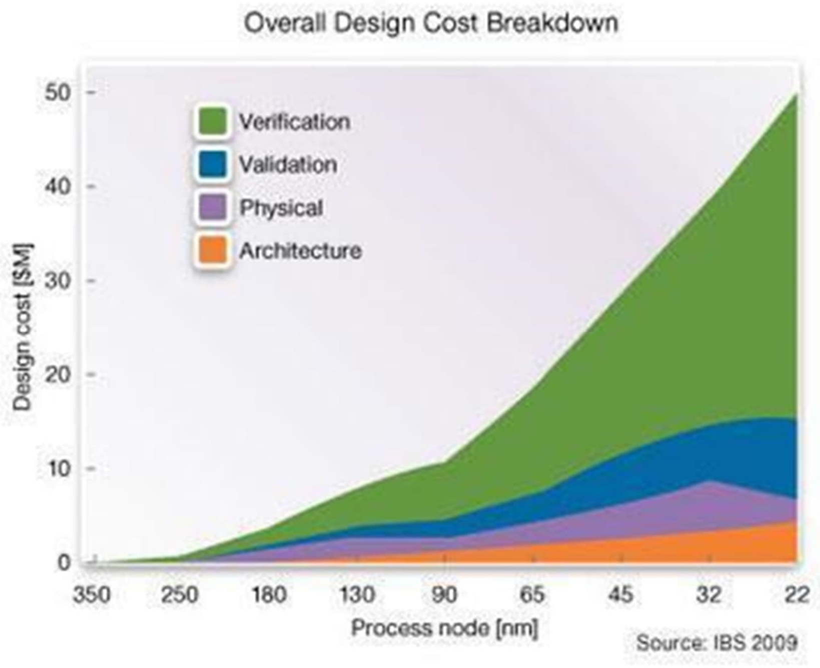

Figure 20. Overall design cost breakdown for the latest manufacturing processes. As the chips grow more complex, the size of the transistors (the process node) must decrease (Sanie M., 2009).

6.2 VIPS in the Market

VIPS could be brought to market in a couple of different ways. The easiest one would be to sell the patent outright and hope that the buyer implements it in one of their products. However, the project owner and the scientists have already rejected this strategy. The goal is instead to build a company based on the patents that can generate long-term revenue.

One option that the project owner wanted to investigate was the possibility to sell complete chip designs. However, this does not seem like a viable strategy at this point. First of all, the design of a new chip would cost at least $50 million and require between 50-100 people. Finding investments for such a risky and costly project would be hard; especially considering how early VIPS is in its development at the moment. Secondly, the competencies needed for such a project would probably be hard to find in Sweden (Radovic, 2013).

For these reasons, licensing out the technology was deemed to be the most suitable business model. To what extent this license would be exclusive to the buyer, and if VIPS would also take royalties for its sales, is not addressed in this section, as it does not impact which markets to analyze.

At the time of this study, it was not yet determined at what level of the value chain VIPS could be implemented. One possibility would be that it has to be integrated at the architectural level, which would leave the project with quite a limited number of potential customers. However, the most likely scenario is that it can be implemented at the chip design level as well. As this is the scenario which calls for a more thorough market analysis, it was assumed that this was the case. If this assumption is false it will only impact this study by rendering it more comprehensive than needed.

Which markets to target, and how to approach them, ultimately depend on the needs of the markets and how these match up with the benefits that VIPS could potentially deliver. For this reason, features of the protocol were investigated to determine what benefits they could translate to. Thereafter, a number of potential applications were identified and studied to determine what value VIPS could deliver for each application.

The potential benefits of VIPS can be classified as either product improvements or process improvements. Product improvements constitute changes in the product or enables new products. This could in turn lead to larger volumes being sold, or that products implementing VIPS could demand a higher price. Another possibility would be that it could open up new markets. The extent to which a producer can benefit from this would ultimately depend on the demand for these features by their customers and third party developers. To determine the features value it would therefore be required to study how these players value them and how the interaction is between the producer and its users.

A process improvement would make the process of bringing a product to market more efficient. This could be in the form of reducing the amount of raw materials needed, or by streamlining the design and production process. This could in turn minimize the cost of materials and design costs, as well as reducing the time to market (**TTM**) for new products. Primarily, this would translate to higher margins for the producer but could also benefit their customers through lower prices and shorter ordering times.

Based on the above classification, a more thorough review of the potential benefits of VIPS will follow. The results are then summarized in Figure 21.

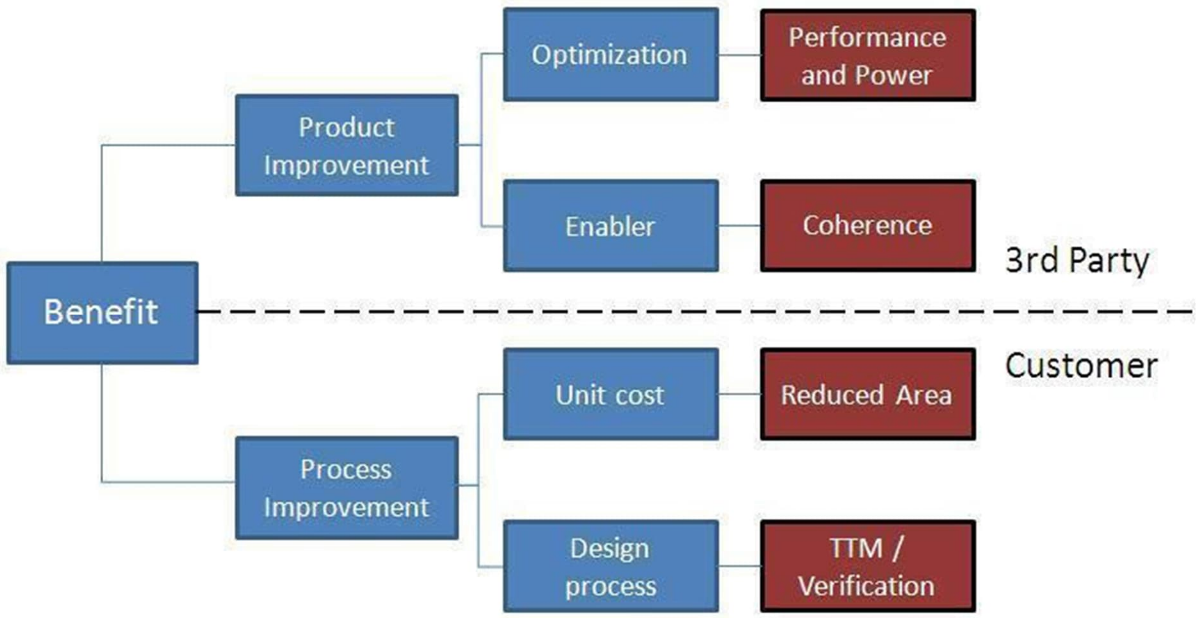

Figure 21. Classification of potential benefits of VIPS. The line separates the players who would ultimately receive the primary value.

6.2.1 Product Improvements

Performance: According to the simulations that have been performed so far, VIPS could improve the execution time for programs running on multiple cores. The only simulations that have been performed so far have been on 16 cores, where the average speedup was about 5%. Theoretically, the improvement increases with the number of cores used and the protocol's ability to scale well was early identified as one of its main benefits. However, this is yet to be verified and no data exists on how it performs for MPUs using fewer or more cores than 16.

Energy Efficiency: As has been mentioned before, simulations indicate that VIPS can reduce the power consumed by the memory system. For a 16-core processor this reduction should be about 20%. For MPUs using fewer cores this figure is likely lower, while theoretically it could be higher when more cores are used.

It should be noted though that it only reduces the power used by the memory system. The total power reduction is lower, as the processor also requires power for its arithmetic operations and control logic. Also, the system in which the MPU is implemented has to be taken into account. In some cases, the processor's power consumption is but a fraction of the system's total consumption, in which case the added energy efficiency is a very marginal benefit.

Enabling cache coherence: For some applications, the need for cache coherence is not enough to warrant the added complexity such a protocol implicates. E.g., this can be true for application specific hardware with many small cores. In these cases, it is usually more efficient to manually manage every piece of data than to implement cache coherency. However, processors such as GPUs that have traditionally been application specific have come to be used for more general purposes. In such cases, a protocol for cache coherence could greatly simplify the programmability of the device, since coherency does not have to be handled by the programmer. The benefit of this is greatly increased if there are third party developers using the processor, as it helps grow the surrounding ecosystem.

VIPS can also simplify the integration of systems with many different kinds of processors, so called heterogeneous systems. This would enable many different processors to share the same memory and execute processes in parallel.

6.2.2 Process Improvements

Area Reduction: As VIPS removes the need for a directory and reduces the number of TLBs needed, the memory system's area decreases. This translates into lower cost of materials for the chip. The area needed is estimated to decrease by 0.75 mm2, which according to experts in the industry would translate to roughly ¢8/chip (Wolf T., 2013). The significance of this will obviously depend on the volume of units sold, as well as the price per unit. The higher the volume and the lower the price, the more important is the cost of materials.

Simplified verification: A feature of the VIPS protocol is that it is comparably simple and classifies data in fewer ways than traditional protocols. These classifications, or states, are used to keep track on the validity of the data and if other caches are storing the same information. While not verified by the researchers, the authors have found indications that this reduced number of states can potentially simplify the verification process. According to Mirit Fromovich of Cadence, a verification tools provider, every combination of transaction and response types, domains and cache states needs to be verified.5 (Fromovich M., 2012). As verification costs quickly increase as the number of states increase a simpler protocol could significantly reduce the number of combinations that need to be verified (Kaxiras S., 2012). The fact that cache coherency does pose a significant problem for verification has been further highlighted by industry reports, and it has been suggested that current protocols need to address these problems in the future (International Technology Roadmap for Semiconductors, 2011, p. 20).

The potential of simplified verification was further investigated by having interviews with people involved in chip verification. When asked what difference a simple protocol would have on verification, the Vice President of Synopsys (a company specializing in verification tools) Joachim Kunkel commented:

> "Huge difference probably. You need to go through the entire state space which results in an explosion of work as the number of states increase." (Kunkel J., 2013)

A research group at Uppsala University was also consulted. They have been involved in the formal verification of the VIPS protocol and confirmed that a reduction of states should simplify verification. However, they also mentioned that there are fewer constraints on the data in VIPS. This can increase the "behavior" of the data and more work has to be put into ensuring that it adheres to specifications. At this point it was therefore hard to say if VIPS would be easier or harder to verify than other protocols. They also pointed out that they only have experience from academia and that the verification process in industry probably involves more testing.

If the process could indeed be simplified it would likely be an interesting selling point. The chief scientist at Tensilica, Grant Martin, pointed out that verification of coherency protocols is a huge problem today and makes up a large part of the verification process of new chips. As all functionality has to be verified, this poses a significant constraint on the whole design process. Simplifying this process could thus enable new functionality, as well as reduce both design and verification costs. Furthermore, verification is today the primary constraint on time to market, which is a key metric in the industry.

While no exact answers could be found at to what degree VIPS could simplify verification, it was concluded that it had a potential worth further research. It was also confirmed that if this was the case it would be a good selling point when approaching customers.

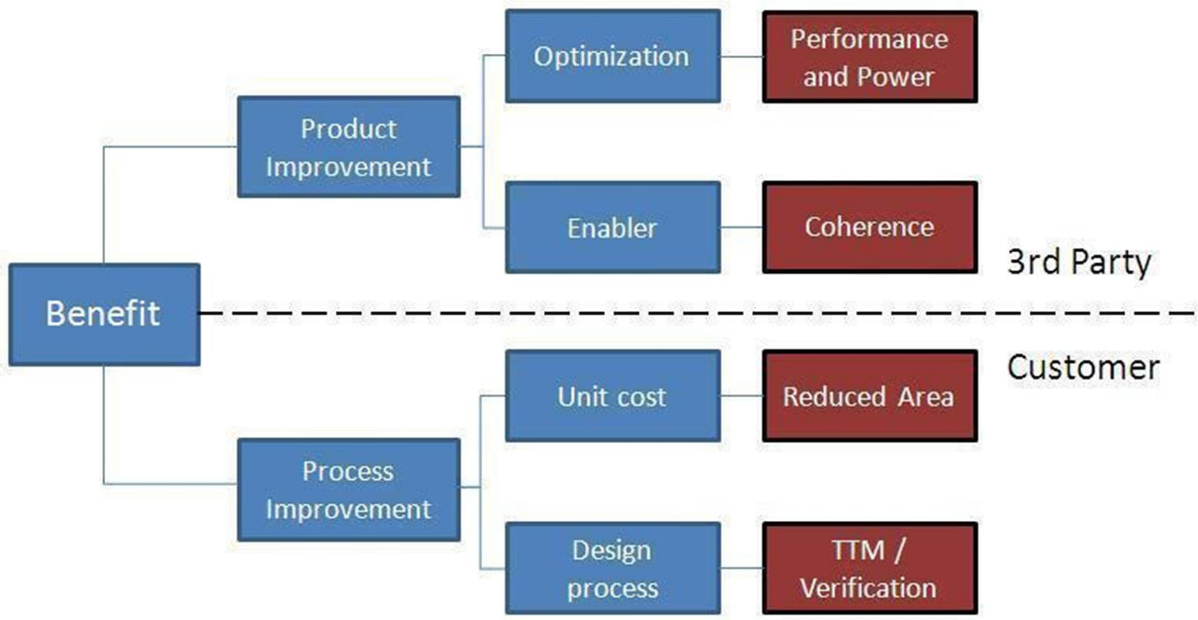

Figure 21. Classification of potential benefits of VIPS. The line separates the players who would ultimately receive the primary value.

6.3 Potential Applications of VIPS

As mentioned, the different benefits that VIPS can bring will have different potential impact on different markets and applications. In order to cover all possible applications, a general segmentation of the market was attempted. It should be noted that there are many ways to do this segmentation and all of them will create corner cases that might be hard to account for, but such are improbable to contain significant markets. The segmentation was made relying on the three principles outlined in chapter 3. A given market segment should have similar drivers, the research and development strategy required for a given market segment should be uniform and a segment should be sufficiently large that the start-up can likely be self-sustaining selling to that segment. This section will give a brief explanation of the different markets, how VIPS could be implemented and what benefits it would bring.

6.3.1 Desktop CPUs

This segment includes CPUs for devices traditionally regarded as “computers”: laptops, desktops and servers. It also includes CPUs that are used to make supercomputers, as long as the CPUs themselves are developed mainly for regular computers. This is because these CPUs have similar drivers and R&D strategy requirements as the rest of the segment. Today this segment consists almost exclusively of advanced and highly developed CPUs based on Intel’s x86 architecture (Paliwal, 2010). This market is characterized by high dependence on legacy compatibility and an urge to defend the low-energy segment from further incursions from designs based on the ARM-architecture.

Most modern CPUs, whether used in servers, desktops, laptops, smartphone or even embedded systems implement cache coherency of some kind. Due to the few different designs produced for this market and their close similarities to previous generations of products, benefits of a simplified verification process are likely relatively low in this market. Thus, the possible benefits of VIPS in such systems are mostly optimizations in PPA. Area is always important in the way that it can be translated directly into production cost and this market has the volumes needed for that to be interesting. On the other hand unit price is relatively high and thus it would only have a marginal impact on the profit margins. Energy efficiency is generally not as important in this segment as it is in others. The CPU is also a comparably small component in the energy footprint due to the fact that computers have a large amount of other parts, such as hard drives, monitors and optical disk drives. Concerning performance, initial simulations show that VIPS is slightly better than MESI, but not by enough to provide a significant advantage.

For a company to invest in a new technology only based on performance gain, the principle “10x” is often used (Goodacre J., 2013) (Radovic, 2013). This means that an invention must show possible improvements of at least ten times better than current technology in order to be of interest. This is due to the high costs of implementing new technology and the fact that the companies usually have roadmaps for new products extending several years into the future. Therefore VIPS do not seem to bring any significant benefits to this product segment. Since the x86 architecture does not presently require data race free code, the potential effects of a protocol that does form a huge barrier of entry into this market. The enormous ecosystem centered on Microsoft Windows, and also Linux for much of the server market, would make it almost impossible for any company making x86 processors to endanger backwards compatibility. A case showing this is the Intel Itanium line, which targets high-end servers but is not completely x86 compatible. After more than a decade on the market, Itanium have failed to gain any momentum at all and sales have repeatedly been far less than forecasts have predicted (CNET, 2005).

6.3.2 Mobile CPUs

The term “Mobile CPUs” is not widely used and sometimes it refers to laptop computers. Here, it is defined as general-purpose application processors for smartphone, tablet and similar implementations. For historical reasons, these are often classified as embedded products but today they have much more in common with desktop CPUs due to their increasingly large ecosystems of third-party code and steady march toward higher performance. ARM and other RISC-architectures, which dominate this segment, have fewer problems with the data race free requirement of VIPS since several of them already impose similar restrictions. However, while data races should not occur in theory, problems may arise in actual implementations and the exact implications thus would need further research to understand (Leonardsson C., 2013).

The PPA-benefits might also be slightly more interesting for this market segment. As these devices use batteries, power efficiency is crucial and VIPS improvements in this department could be of interest (Courtland R., 2012). Also, the reduced area requirement would mean lower production costs and the fact that the reduced area also would imply a smaller chip overall could be of interest to markets where space is more valuable.

6.3.3 HPC

High Performance Computing, HPC, is often called “supercomputers” and refer to computer clusters that are specifically designed to perform advanced calculations or handle enormous amounts of data. HPCs have very many processing nodes with each node containing several cores. Coherence is a big issue in such systems. It would be reasonable to think that VIPS could be beneficial in this application; since the nature of VIPS as a protocol with very small requirements on hardware and little use of signaling to enforce coherence imply that the improvements over established protocols should improve as the number of cores increase (Radovic, 2013). This has, however, yet not been proven either theoretically or through simulations. The benefits from this could be assumed to be in both performance and power, aspects that are of great importance to HPCs.

There are many different kinds of HPCs but two major design paradigms exist: either a HPC is constructed using parts that are based on consumer products or components specifically designed for the HPC market are used. Some HPCs are even made from components that are designed specifically for that very computer, but those are covered below under “Customized Processors” since the drivers in that market segment line up better with the drivers of customized HPC processors. Using parts based on consumer products is usually cheaper but has drawbacks in that it might be hard to optimize such a system for maximum performance or power efficiency. As parts get more specialized, the relation is inverted. Many world-leading HPC makers use some kind of hybrid approach (Top500.org, 2012).

The HPC components that are used in consumer products as well generally make more money from their “day-job” (Dally W., 2013) than from HPC usage and the development of these products is closely related to the benefits to their respective consumer market. Such products include CPUs for desktop and potentially mobile as well as GPUs. Since the market drivers for such components are fundamentally different from those products built for the HPC market, we exclude those from this market and study these in the GPU and CPU markets respectively.

Components used exclusively for HPCs on the other hand have, as a market, much in common with desktop CPUs, including requirements of legacy compatibility (Monchalin E., 2013). Since large amounts of code have been optimized to perfection as much as several decades ago, this requirement is even more formal than for consumer CPUs and perfect legacy compatibility is a selling point in itself.64 This is in part due to the fact that many HPC-systems are in some degree used to rent computing power to others than the owners of the system. With the rise of cloud computing, this is predicted to be even more important in the future (Fredette M., 2012). Another problem is that the HPC makers generally have very little control over the development of future products (Monchalin E., 2013).

6.3.4 Embedded

As has been mentioned, it is hard to draw a definitive line between CPUs, microprocessors and microcontrollers. This is again true for the term **embedded**, which can sometimes be used to describe anything that is not a traditional computer. Originally, it referred to simpler, application specific processors embedded in larger and often non-electronic systems. The processor switching the traffic light on and off would be an example of such a system. Unlike a general processing unit found in a computer, it has only one task and can only receive instructions relating to this task. However, as technology has evolved many devices that were once application specific can now perform tasks of a general nature. An example of this would be mobile phones. As the mobile market has radically different drivers and R&D requirements from e.g. the industrial market, the term embedded market will from hereon be used to describe the non-mobile embedded market.

For VIPS, there is a possible application in such advanced microcontrollers. This market could be characterized by processors that are advanced enough to have more than one core but end products that are very specialized and therefore do not use much legacy or third-party code. This segment sees comparatively many new models released from more companies than do the market segment for larger CPUs. The benefits from PPA would differ very much between products but since the systems are relatively simple and the number of cores is low, performance is unlikely to be impacted. As with mobile CPUs power and area might be interesting, especially area since the price per unit often is low.

The potential for simplified verification might be very interesting to companies making advanced microcontrollers for embedded systems.

6.3.5 GPU

Modern GPUs for desktop and laptops contain up to several thousands of relatively simple cores. This makes them ideal for highly parallelized tasks on large sets of data, such as graphics. While graphics is still the most common task of GPUs they are also used for many other tasks, such as physics simulations for games and calculations for research and industry.

Using GPUs for these purposes is called general-purpose GPU programming (**GPGPU** programming) and is a rapidly growing market (Gupta A., 2003).

GPUs do not currently use cache coherence, partly due to the fact that it would be very impractical to fit a TLB beside every little core as would be required by MESI. Since VIPS can work without distributed TLBs it is one of the first protocols that could enable coherence within GPUs (S. Kaxiras 2013b). While cache coherence is not of interest for pure graphic generation it might be of great use to GPGPU programmers. Today, GPGPU adoption is stalled by the high demands it places upon the programmers and solving this problem could potentially grow the market (Wainwright I., 2013).

6.3.6 APU

An emerging class of products is APUs, systems where the CPU and GPU parts are completely integrated. More generally, this kind of system can also be referred to as heterogeneous systems. This means that they share the same memory and that threads can be executed on either type of core without special management. The usage of the term APU thus implies coherence in both CPU and GPU. VIPS could provide this with one unified protocol, while other solutions would need different protocols and some translation between them. VIPS also simplifies virtual addressing, not only for the CPU and GPU respectively, but also for the entire system. The APU market is therefore defined as the market for a full solution of coherence to enable an APU, such as illustrated in Figure 22.

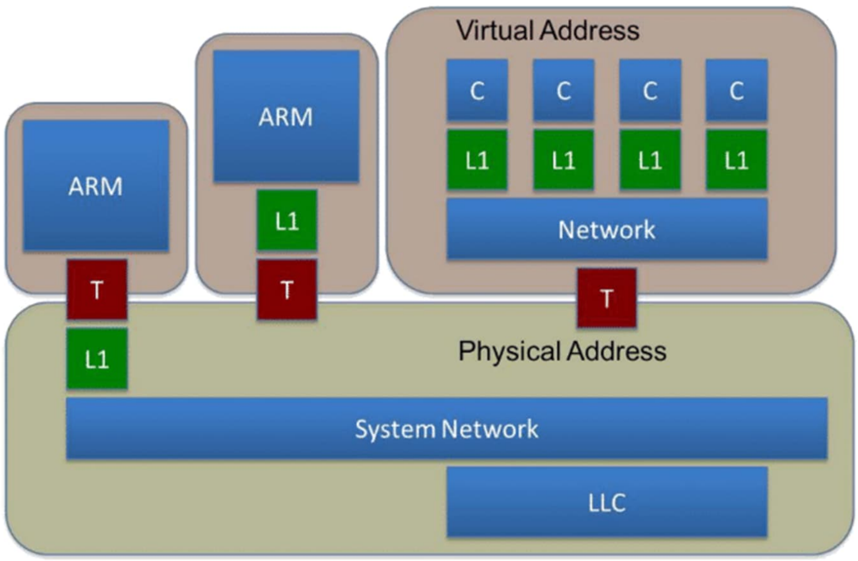

Figure 22. Schematic view of how a heterogeneous system could be designed. VIPS could enable coherence for the entire system, which would be almost impossible using MESI. (Kaxiras & Ros, 2013b)

The leading force behind the current development is AMD, which has started the HSA (Heterogeneous System Architecture) foundation together with several other important companies (The HSA Foundation, 2012). One problem is that HSA is in the process of finalizing its specifications and the first products are expected to ship at the end of 2013 (Bright P., 2013). This is far too soon for VIPS to be included and while anything could happen in the future, a wait-and-see strategy is recommended concerning a full solution for AMD. AMD is the only company with a stated vision of APUs and they already have a solution. Meanwhile the main obstacle towards an APU for all other companies is coherence for GPUs. This means that pursuing the GPU market must be a first step towards this market and any further study is delegated to the GPU market. It should be noted though that giving a full solution for an APU might very well be the next step from selling coherence for a GPU.

6.3.7 Customized Processors

While the absolute majority of processors used today come from some major product line, there do exist cases where chips are manufactured for just one or a very small number of systems. These can be found in extreme conditions, in academic research projects or within ongoing research and development projects (Haglund M., 2013). It is very difficult to know exactly which aspects of VIPS would be most interesting to a customized customer but these systems would likely benefit more from the scalability aspects of VIPS rather than process improvements.

While these customized projects are few and hard to find, they truly represent the innovators, or enthusiasts, of the industry and they might benefit greatly from the ability to implement coherence in a new way. Such a project would likely not need to worry about legacy compatibility as it is built from scratch for a specific purpose.

6.3.8 Summary of Benefits and Applications

The initial findings are summarized in Table 1. Based on these, a number of applications were disregarded as likely first markets for VIPS. The primary reason for exclusion was compatibility issues, as rewriting software and pushing new standards is very costly and hard (Goodacre J., 2013). For this reason the desktop market was deemed unattractive, besides VIPS not contributing any unique benefits in this field. While the performance increase could be greater for HPCs, the same problems with compatibility are prevalent in this market. APUs were disregarded as a first application in favor of GPUs since the companies who might make an APU are either too far along or should first be approached about GPUs.

Of the remaining applications, all were considered feasible enough to be investigated further. The reasoning for this were as follows:

Mobile CPU. The inventors saw this as the initial target market. Also, it had no obvious technical constraints and some potential to benefit from VIPS' features.

Embedded. No obvious barriers were identified and a number of VIPS' features could likely be of interest.

GPU. While VIPS would add some extra complexity and chip area, the potential for a unique new solution could be a strong value proposition.

Customized Processors. The constraints on data races would not be a problem in this market. Also, in interviews with an IBM-representative VIPS was identified as a potential *killer application* in this field (Haglund M., 2013).

Feature \ Application	Desktop CPU	Mobile CPU	HPC	Embedded
Performance	Not significant	Not significant	Likely significant	Not significant
Power	Not important	Marginal	Potentially important	Potentially important
Chip Area	Marginal	Might be interesting	Not important	Interesting
Simplicity	Likely marginal benefits	Verification might be simplified	Verification might be simplified	Verification might be simplified
Virtual Caches	Irrelevant	Irrelevant	Irrelevant	Irrelevant
Data-race free	Incompatibility, legacy problems	In theory irrelevant, in practice?	Incompatibility, legacy problems	Dependence on legacy code is small

Feature \ Application	GPU	APU	Customized
Performance	Might be beneficial	Likely not significant	Improved for some applications
Power	No improvement	Not significant	Improved for some applications
Chip Area	Added area	Added area	Not important, few units
Simplicity	Added complexity	One solution across entire system	Not significant

Virtual Caches	Enables coherence	Enables coherence for GPU	Might be the only way to enable coherence
Data-race free	Not problematic	Incompatibility, legacy problems	Not problematic

Table 1. Identified benefits of VIPS for different applications. Notable post, either positive or negative, have been colored.

6.4 Attractiveness Metric

To further investigate the potential applications of VIPS, an analytical framework was created. This framework was not based on previous research, but used input from industry experts on what they considered important when evaluating new technology, as well as factors determined significant by the project owner. The input suggested that the primary challenge of VIPS would be to find a first customer who would be willing to take on the risks involved with the technology. Therefore, the framework was designed to include an evaluation of the potential for a first customer in the market. To analyze the market's profitability for VIPS, it also included the value a first sale would bring and the potential for expansion once a first sale had been reached.

The framework used the common concepts of value creation and value capture, which formulate what value a firm can deliver to its customers and what share of this value can be retained by the firm. Traditionally, created value is defined as benefits - costs, where costs include both the costs of acquiring the product and the opportunity cost of doing so (Fischer T., 2011). In this case the related costs were found to be dominated by switching costs and other barriers to entry rather than costs associated with the purchase and use of the technology. For this reason, created value was defined as the benefits to a customer applying VIPS, without taking switching costs into account, and barriers to entry were defined to include switching and development costs. Captured value is defined as percentage of the created value VIPS could derive from a first sale to a customer. Finally, potential value is the long term potential of a certain market given an initial first sale. A representation of this can be seen in Figure 23.

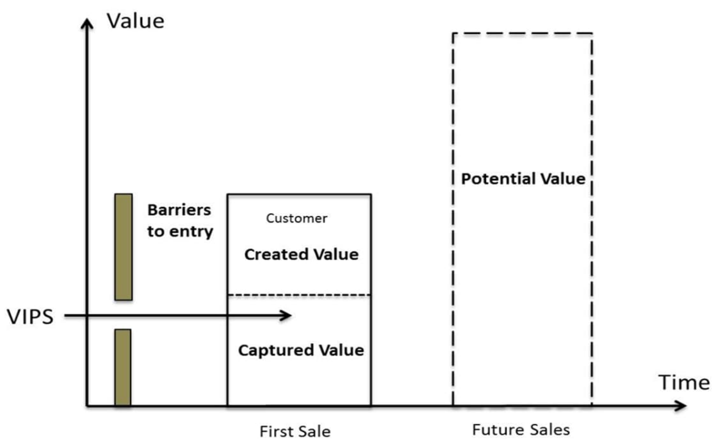

Figure 23. The indicators used to form an attractiveness metric.

When evaluating the four indicators, a number of different factors were analyzed. A short description of these follows below:

- **Barriers to entry:** A number of factors could limit VIPS potential to enter a market. Perhaps most importantly would be the degree to which a customer would have to re-write software and develop new tools. Related to this would be how complicated the market's ecosystem is and what control of it a potential customer has. Other factors would be the propensity to work with academia and "not invented here" factors, referring to the unwillingness of many companies to accept inventions from the outside.
- **Created Value.** What value could be created depends on what benefits could be achieved and how these benefits would be valued. A wide range of factors could be considered, e.g. the number of cores in a typical application, the processor's share of a typical system's power consumption, the average price of a chip and the number of different processor designs. To estimate the value of such benefits, interviews, reports and surveys were used. Study of companies future roadmaps were also referenced as they give an indication of what features are valued by the market.

- **Captured Value.** The value VIPS could derive for a first sale would depend on the bargaining position of VIPS. The number of potential customers and their size would be important metrics. Another factor would be the chances of a customer requiring exclusive licensing rights. The degree of asymmetric information could also play a role as for some applications it could be hard for VIPS to estimate the value it creates.

- **Potential Value.** To determine the long term potential, standard metrics such as market size, growth and purchasing power was evaluated. Also, the ease of acquiring future customers and substantial sales volumes were considered.

6.5 Market of Chosen Applications

In this section we evaluate the chosen application segments with regards to the attractiveness metric described in the section above.

6.5.1 Mobile CPU

The market for CPUs in mobile applications is dominated by high-end ARM-based designs (ARM Holdings plc, 2013, p. 16). The business model of ARM is to develop an instruction set and architectures and then sell licenses for these. Currently, no attempts to construct an ARM processor using VIPS have been made and therefore it is hard to tell on what level it would be possible to integrate the technology. If it is only possible for ARM themselves to do this, there is basically only one potential customer. If this can be implemented by ARM license holders, there are a lot more companies involved, e.g. Apple and Qualcomm. As a whole, the market is growing rapidly at about 46% per year (Columbus L., 2013) but this growth only increases the problems associated with ecosystems and economies of scale. The selected indicators are evaluated below and summarized in Table 2.

Barriers to Entry: The mobile CPU market is deeply entrenched in ecosystem dependencies, as is clearly seen in the distribution of main OSs and their accompanying third-party support. In the first quarter of 2013, more than 90% of all smartphones sold carried one of the two major systems: Apple's iOS and Google's Android (IDC, 2013). The switching costs associated with breaking legacy compatibility would be enormous and even if it could be proven theoretically that VIPS would not do that it is reasonable that companies would still be hesitant to implement such a radical change, especially when the invention comes from outside the company and from academia (Goodacre J., 2013).

Created Value: The power-savings shown in the simulations could imply an improvement in battery life of about 2% (Carroll A., 2010), which is likely not enough for a company to make the expensive switch to a new coherence protocol. The process improvements could still be interesting, but relatively few designs are produced due to the fact that most makers of SoC products use pre-designed ARM CPUs (ARM Holdings plc, 2013 p. 17). Therefore, the savings would not be as significant as in markets with more designs produced each year. In total, it is unlikely that VIPS could really create any significant value for a company in the mobile CPU market, a sentiment that was echoed by ARM Director of Technology and Systems John Goodacre.

Captured Value: Too much is unknown regarding the technological feasibility of different strategies to say anything certain, but in the case that there would be only one potential customer VIPS would have a difficult bargaining position. If there are more companies that could implement the technology the situation would be more beneficial, but on the other hand the customers are more likely to require an exclusive license to prevent their competitors from obtaining this product improvement. The fact that the envisioned created value is low is obviously a limiter to what VIPS could gain.

Potential Value: Since the market is already big and growing rapidly, a successful first sale could mean huge growth within a relatively short time. Although this market has a huge potential in the long run, it is not a good candidate for a first sale. It is, however, not impossible that it could be entered at a later stage when the technology is more proven. In particular an entry from the microcontroller industry could be rather simple due to the similarities in the technologies used.

6.5.2 Embedded

Although not as visible as the computer or mobile market, the embedded market is by far the largest one when looking at the volume of units sold. About 98% of the world's microprocessors are sold in the form of microcontrollers to be used in embedded systems. However, as the designs are typically simpler and performance is lower, the unit cost for microcontrollers is comparably low. Still, total sales in 2013 are estimated to amount to $25 billion or about

30% of the total market for microcomponents (IC Insights, Inc, 2013). According to forecasts this market will grow even bigger and reach $28 billion in 2018 (Transparancy Market Research, 2013).

Traditionally, relatively simple microcontrollers have dominated the market. However, increased demands on performance and lower prices have increased the use of more advanced devices. Multi-core microcontrollers have gained ground, with around 15% of MCUs now making use of more than one core.84 This is especially true for areas such as automotive and networking where some applications use devices similar to traditional CPUs (Freescale Semiconductor Inc, 2013) (Coupé C., 2011).

As microcontrollers are used in a wide array of applications, each with specific requirements, there are good possibilities for companies to create a niche for themselves for certain applications. This has caused a rather fragmented market with comparably many companies sharing the revenue, see Figure 24.

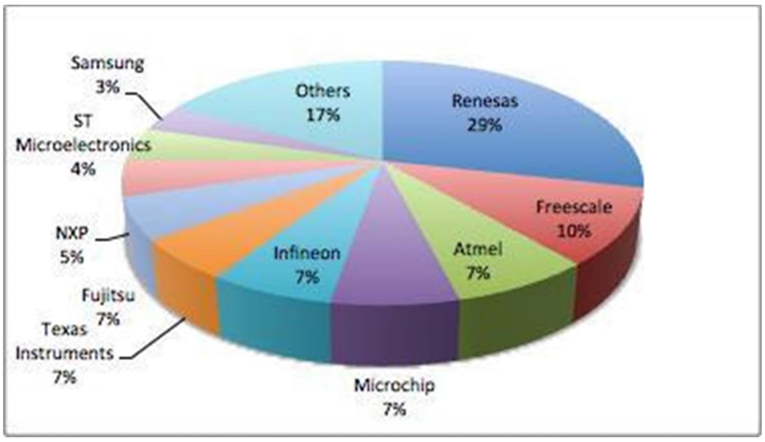

Figure 24. Market share of microcontrollers in the embedded industry. (Heikkila E., 2009)

Unlike the mobile or desktop market, a number of different architectures are still being used. While the trend seems to be that more and more chips become ARM-based, many of the leading companies still have product lines based on other architectures. Thus, in the case that VIPS is not ARM-compatible there would still exist potential alternatives in this market.

A primary reason why many different architectures are still viable is that MCUs are to a large degree application specific. A big part of the software it runs is developed by either the chip designers or their customers, rather than by third parties. Thus, hardware developers have to worry less about supporting different standards for the final product. In this sense, compatibility and support of legacy code is of less concern in this market than in others.

Market Drivers: For the customers purchasing microcontrollers, not only the product features are of importance. In a recent survey performed on 2000 designers of embedded systems, only 42% mentioned a product's general features as the most important factor when choosing a microcontroller. Slightly more people (45%) instead mentioned the ecosystem surrounding the chip in terms of development and debugging tools as most important. A similar preference was evident when asked to specify what individual features were considered, as can be seen in Figure 25.

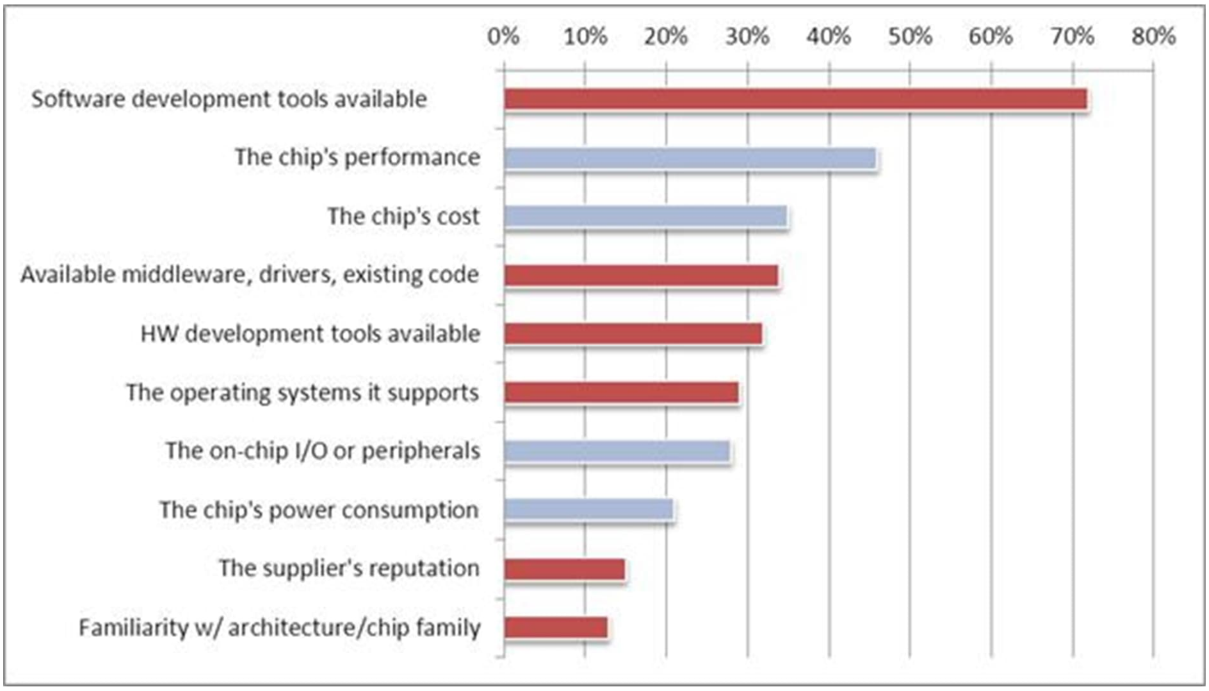

Figure 25. Embedded systems designers' main reasons for choice of microcontroller. Features not related to hardware are colored red. (Blaza D., 2013)

As can be seen, the by far most important factor is that software development tools are available for the chip. While the features of the chip are important, the tools to actually make use of these and being able to seamlessly integrate the chip into the whole system is of even greater importance. Along the same lines, the existence of drivers, hardware development tools and compatibility with operating systems are key factors to consider.

Surprisingly, energy efficiency is only ranked in 8th place. Despite being one of the key metrics normally used for microchips, there are clearly other factors that are more valued by the customers. When looking at drivers for the designers of the actual chips, other factors come into play. One example is the importance of flexibility in the design process. To better optimize chips for specific needs, chip designers continually have to improve their processes for easy and cost efficient modifications (Renesas Electronics America Inc, 2013). Related to the flexible design process is the importance of reducing time-to-market. This has a large impact on market share, which both leads to larger revenues and lower unit costs due to economies of scale (Rowe K., 2010).

Barriers to entry: The high importance of a well-developed ecosystem of design and integration tools could pose a problem for VIPS. In case of compatibility issues, huge amounts of code would need to be rewritten. However, if compatibility could be ensured this would reduce the demands for new software as they can utilize the ecosystem of their customers.

The high degree of application specificity of MCUs could prove beneficial to VIPS. Unlike general purpose processors, little legacy code needs to be supported for these applications. Also, few 3rd party developers exist that are dependent on certain standards. This causes key players to have big portions of software control and new standards can be pushed comparably easy.

The relatively small reliance on scale also works in VIPS favor. For complex design projects that rely on very high volumes to recoup costs, companies' are hesitant to bring in new and unproven technology as there is too much risk involved. While still significant, this problem should be smaller in this market.

Created Value: While the demands for performance have increased, it is unlikely that VIPS could bring sufficient benefits in this regard as the number of cores are still relatively few for most applications. Neither does the improvements in power efficiency seem enough to target this market. VIPS greatest prospect of being relevant in this market would rather be as a process enhancement. Lower costs due to reduced chip size could be interesting for simpler multi-core MCUs. These chips are comparatively cheap so a reduction in cost of materials could have a relevant impact on the margins. Even more promising is the potential for simplified verification. The embedded market has far more product offerings than other markets, which makes a flexible and cost efficient design process a key competence. The benefits of a simpler and faster verification process would therefore be fourfold:

1. Added flexibility. By simplifying the process, more offers can be tailor-made to target specific needs. This ability would be highly attractive given the high level of customization required by their customers.
2. Reduced costs. The large number of different designs makes this process an even bigger part of the total costs. Decreasing the costs of the design process would cumulatively lead to large cost reductions.
3. Increased reliability. When verifying a new chip, not all aspects can be taken into account. By reducing the cost of verification, more in-depth verification can be done and the reliability of the product can be improved.
4. Decreased time-to-market. TTM is very important in the embedded market to both increase revenue and to utilize economies of scale. However, this consideration is generally seen as even more important in mass markets with "winner-takes-all" dynamics (Rowe K., 2010).

Captured Value: In this market, VIPS would likely constitute a process enhancement rather than a product improvement. Therefore, offering a non-exclusive deal is likely possible as its value is only marginally dependent on its exclusivity. Unlike product improvements, its value is not derived from increased market share and thus it is less affected by a competitor acquiring it.

The fragmented market should also benefit VIPS by not forcing them to be too reliant on one player. In negotiations, a potential customer knows that there are other alternatives which should increase the chances of striking a better deal.

VIPS greatest challenge in negotiations would be to evaluate and communicate the value of their invention. The exact impact on the verification process would differ between different companies. This could lead to an information disadvantage where it is hard to quantify and get proper pay for the value that is added. Also, communicating the value might prove harder than easily quantifiable properties like performance and power.

Potential Value: In the case of a first sale being made, future profitability is still not a given. The fragmentation of the market makes a single customer within a certain application not enough to ensure long term profitability. Also, the sales overhead of targeting many different small customers can potentially be a large cost.

However, the market is growing at a good rate and if VIPS can prove itself it should have a good potential to capitalize on this growth. Companies like ARM have shown before that it is possible to start as a niche player in the embedded market to continually grow and compete in new markets.

6.5.3 GPUs

The market for GPUs has been experiencing a healthy growth since 2001 as shown in Figure 26. As noted in the technology discussion, VIPS has nothing to offer a GPU working only with graphics, but rather GPUs involved in general purpose calculations, GPGPU, such as calculations for game physics or scientific research. Modern PCs have integrated graphics cards and GPUs are increasingly being used for other purposes than graphics, which has spurred the market growth. Since GPUs in mobile phones currently aren't used for these calculations, the market studied excludes these GPUs except when discussing the effects these GPUs have on general market drivers.

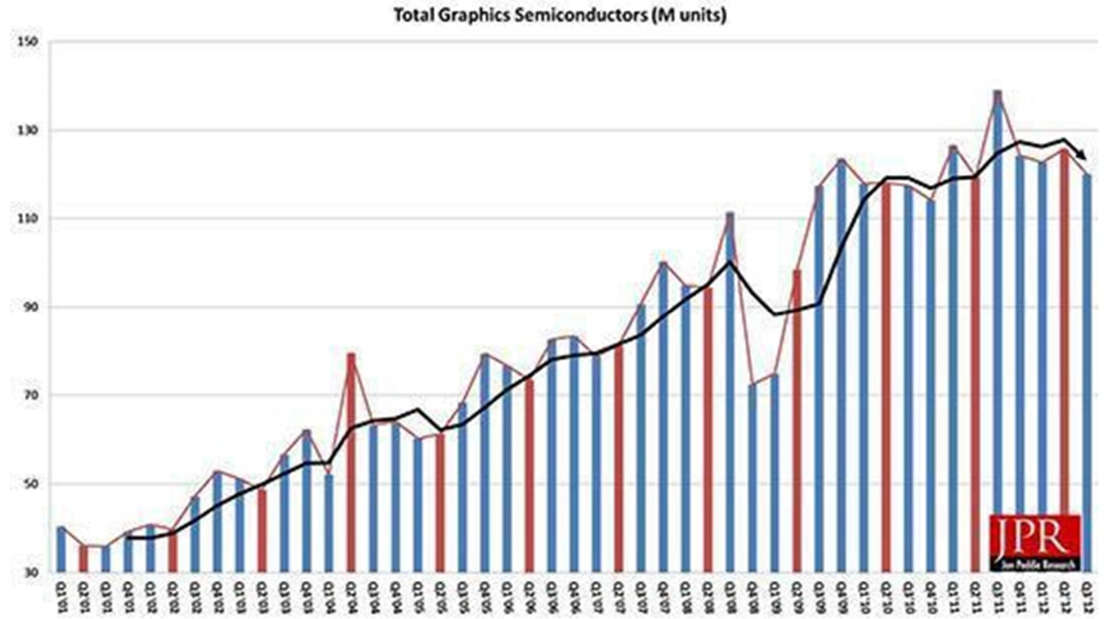

Figure 26. The GPU market has experienced a healthy growth since 2001. (Jon Peddie Research, 2012)

The GPU market is dominated by NVIDIA, AMD (who have acquired ATI) and Intel. This means that a study of this market is necessarily a study of these three players. All of Intel's GPUs and the majority of AMDs GPUs are sold on the same chip as a CPU, a so called **integrated** GPU. This makes market size in terms of dollars is impossible to evaluate and the data available are always on the number of units sold. The translation from these numbers to dollar share of the market is very complicated since the GPUs sold on separate chips, so called **discrete** GPUs, are much more advanced and higher priced. The number of units sold can however give a good picture of the market when combined with a discussion of price and growth of market segments.

Measured in number of units sold Intel leads at 61.8%, AMD has 20.2% and NVIDIA has 18.0% of the market. This domination by Intel is due to the replacement of discrete GPUs by integrated, which has taken place in the desktop and laptop markets. The emergence and achieved dominance of integrated GPUs can be seen in Figure 27.

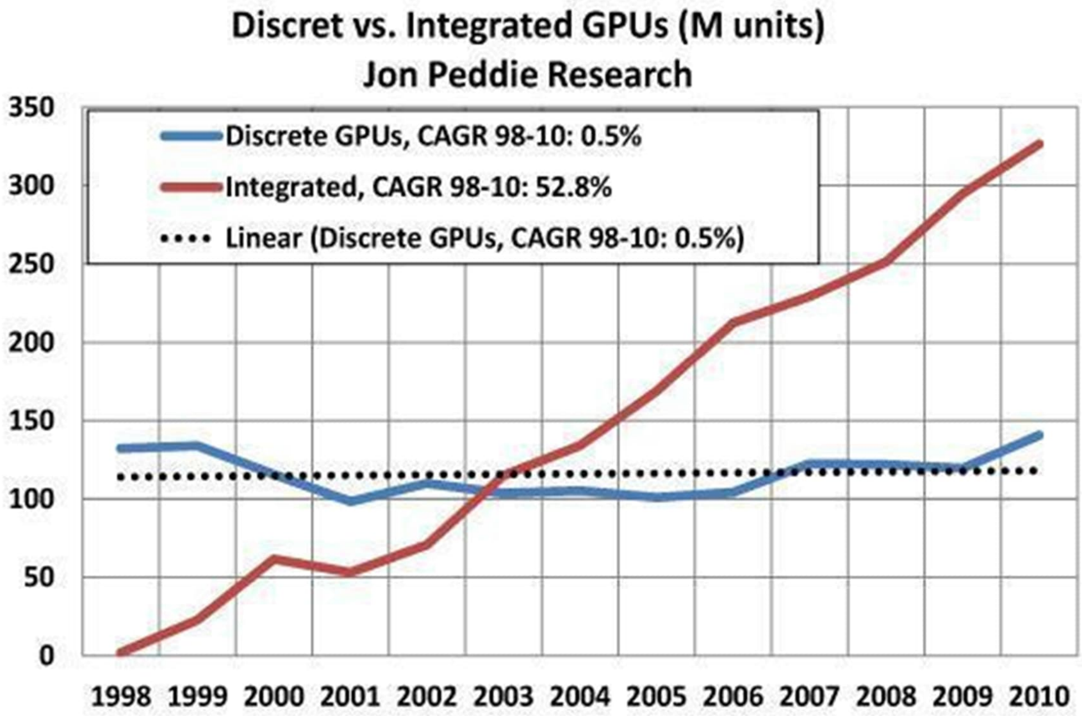

Figure 27. While the entire GPU market is growing fast, integrated GPUs have been stealing the low end market from discretes causing the sales of discretes to remain stagnant. (Jon Peddie Research, 2012)

While it is apparent that integrated GPUs has been the growing segment for quite some time, this growth is in the lower end segments of the market. This means that the stagnation of discrete cards is a consequence of a market which grows quickly and a trend to replace discrete GPUs by integrated GPUs in low-end segments.

Intel is historically a CPU vendor, but have since long had small integrated GPUs. These have been named simply as HD Graphics followed by a number and there has been little effort to create a recognizable brand. With the next generation of Intel processors they are releasing their first branded GPU, named Iris (Fingas J., 2013). Iris is more than twice as fast as previous versions and the aim is to further drive discrete GPUs from the market. While Iris is no way near the performance of the AMD and NVIDIA discrete cards, it does create a situation where fewer consumers need to add a discrete GPU and thus Intel will get a larger percentage of the earnings from processors.

There has however been no sign that Intel is interested in GPGPU programming and while Iris is faster than previous models anyone wishing to use GPUs for complicated calculations would add one or more of the much stronger discrete GPUs. However, with Intel’s continuous push towards stronger GPUs there might be a future interest in making these cards easier to program. This would mean that VIPS could be interesting in the future, but due to lack of information and a lack of any apparent interest from Intel, they have been dropped from the study.

AMD on the other hand has shown a great interest in increasing programmability for GPUs. In a project founded by AMD, Heterogeneous Systems Architecture (HSA), AMD is at the leading edge of CPU and GPU integration. During 2013 AMD has published a paper on a coherence protocol of their own called temporal coherence, which is meant to be used in GPUs (Singh I., 2013). Temporal coherence is based on a similar idea as VIPS but isn't suited for any application other than GPUs and is likely to run well only on GPUs which are currently in the higher end of performance (S. Kaxiras 2013c). At the end of 2013 they are scheduled to release their first cache coherent GPU with coherence implemented in hardware and with a unified memory between the CPU and GPU, named hUMA (Bright P., 2013). Since AMD is so far along in their efforts towards having cache coherence in GPUs, AMD has been dropped as a potential customer and focus has been narrowed to their competitor NVIDIA.

AMD and NVIDIA have long been competing for dominance on the market for discrete GPUs but in the last two years the market has swung heavily in favor of NVIDIA. From having 50% in 2010 to 67% at the fourth quarter 2012 (Caulfield, 2013) as seen in Figure 28 above and the trend continues with NVIDIA gaining even more during 2013. Much of this can be explained by the fact that NVIDIA is focusing on this market and providing better tools for programming for GPGPU (Wainwright I., 2013), while AMD has been focusing on integrated GPUs.

In March 2013 NVIDIA released an updated roadmap which focuses heavily on programmability of GPUs but also reveals that they see an important future in mobiles, continuing to develop their Tegra brand (Caulfield, 2013). What will be coming in their next generation GPUs is the ability to have unified virtual memory between discrete GPUs and the CPU they are attached to. This will greatly improve GPGPU usability as the CPU no longer will have to send for the data it needs from the GPU, it can just access in the same way as it accesses its own memory.

NVIDIA's product improvement process consists of focusing on the supercomputer market and then letting these improvements be included in future generations of desktop and mobile products (Dally W., 2013). New features for improved performance and programmability are introduced in the GPUs for supercomputers. These cards are then sold to the middle range markets at 10% of the prize, but the programmability improvements are delayed for one generation. The GPUs are then adjusted for the next generation of low end mobile products, reducing performance and size considerably (Wainwright I., 2013).

This strategy implies that all improvements made to the high end market also reach the mass markets. Thus new innovations are purchased for the supercomputer market but the benefit these products have for other markets are also considered.

From the data can be seen that even though the three players work in different ways and in different markets, there is a convergence in future products moving towards highly integrated GPUs with a high amount of programmability. The current presence of NVIDIA, AMD and Intel are visualized to the left in Figure 29. It should be noted that AMD is moving to the right focusing on middle range APUs for markets such as consoles and computers, while Intel is moving upwards with the introduction of Iris but also to the right as OpenCL, a GPU programming language supported by all players, continues to be developed. The roadmap of NVIDIA is visualized to the right in Figure 29.

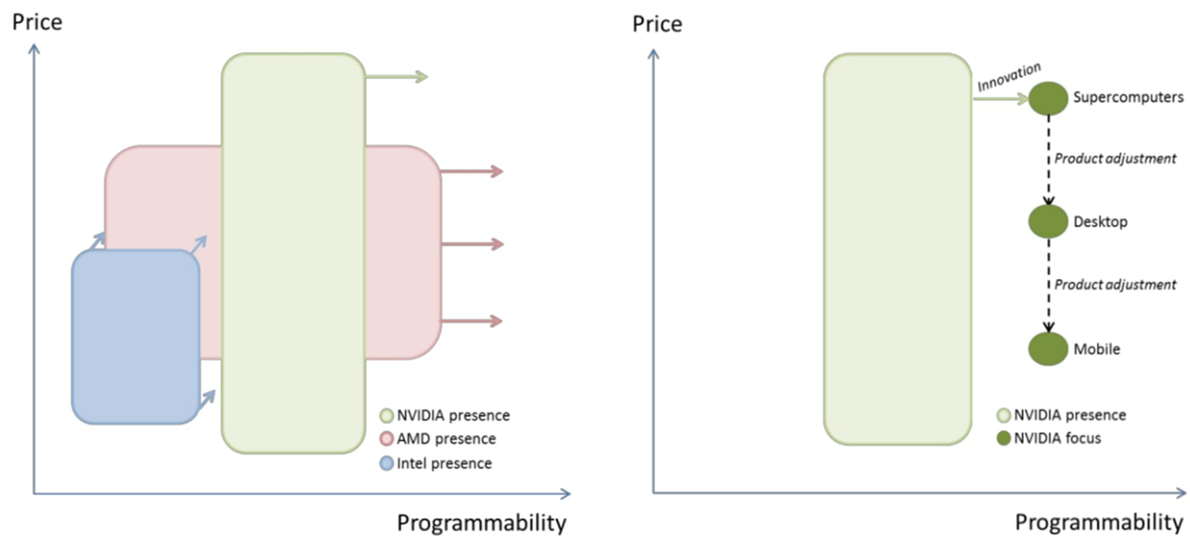

Figure 29. On the left side is a representation of the presence and direction of the players in the GPU market. On the right side we see NVIDIA's development strategy outlined.

In conclusion AMD has advanced too far in their solution and become uninteresting as a customer. Intel doesn't envision high degrees of GPGPU support but cannot be completely dismissed as a customer for coherence for their GPUs. The prospect seems rather bleak but a discussion should be initiated to see if a joint research or verification project could be started. The interesting player in this market seems to be NVIDIA who has a roadmap which fits very well with coherence in GPUs and who has given no indication of having solved this problem. For these reasons the investigation of Intel and AMD is abandoned and the focus is NVIDIA for the remainder of this section.

Having narrowed our focus to NVIDIA, the market drivers become NVIDIA drivers. NVIDIA has long been losing market share in the desktop market to integrated GPUs. Their response has been to focus their efforts towards growing the high end segments of the GPU market by innovating for GPGPU. While a high end graphics card for these markets have relatively small benefits in performance over the middle range cards inserted into desktop PCs NVIDIA charges ten times the price. This is justified by the higher programmability which is crucial to the market due to lack of skilled GPU programmers (Wainwright I., 2013).

The incentive to grow this market, which is almost exclusively owned by NVIDIA, has caused NVIDIA to focus on providing improved software tools to make GPU programming as close to CPU programming as possible. One example of this is CUDA, a free programming language used for programming GPUs which is very similar to C. The barrier to grow this market is the difficulty and cost of recruiting knowledgeable GPU programmers to take advantage of the sometimes 100 times better performance of GPUs over CPUs.

According to HPC (High Performance Consulting), an Uppsala based consulting firm specialized in rewriting code to adapt it to GPUs, NVIDIA listens very closely to GPGPU programmers and every new generation of NVIDIA GPUs come with new tools enabling easier programming. They claim that NVIDIA every generation of NVIDIA GPUs contain new hardware and software solutions which make their job a lot easier. One reason for this is said to be creating an easier transition from traditional CPU programming.

Given that the most relevant challenge to NVIDIA is growing a market which highly values programmability this strategy is not surprising and NVIDIAs roadmap, presented above cements this analysis.

Barriers to Entry: General barriers to entry such as unwillingness to bring in outside innovations may apply but there are also other barriers. One problem which could very well exist is that NVIDIA may be working on their own solution to this problem, and possibly already have one.

Another barrier is the large amount of software tools already built to take advantage of the current architecture which would be very expensive to redesign. The good news here is that CUDA is completely controlled by NVIDIA so that even though there might be a big cost associated with switching, the decision to undertake this effort can be taken by NVIDIA themselves. There might be some problems adjusting for OpenCL which is not controlled by NVIDIA. Overall this problem is expected to be smaller than for the embedded market where the players are smaller and a big investment in software rewrite can be bothersome and where software tools might not be as controlled by the chip designers.

During an interview with HPC it took them a while to relate to coherence. The reason stated was that they are not used to thinking in those terms. Since the current GPGPU programmers are the opinion leaders in this market, any difficulty they have in relating to the product could be a problem.

Created Value: Coherence simplifies programming, which grows the very lucrative high end market for NVIDIA. NVIDIA is highly influenced by the GPGPU programmer community and are constantly implementing the changes they ask for (Wainwright I., 2013). This shows that they are acutely aware of the need for innovation in this area.

Often the success of a programming project is measured in performance per man-hour. While the programmability of the GPU is very important to improve on this metric there are also reasons to believe that a coherence protocol would improve the overall performance on certain tasks. This is because handling coherence in software often leads to an inefficient implementation. By putting the coherence in hardware some of the classification of data which is done at the start of the program can instead be done during runtime which would reduce the overuse of private classifications and thus improve performance (Wainwright I., 2013).

Since AMD is releasing the middle range highly programmable coherent GPUs, NVIDIA may need to make their GPUs coherent in order to compete. If this is the case then VIPS is the only known alternative, except temporal coherence owned by AMD.

There are some drawbacks from inserting coherence into hardware. It increases chip area which translates to increased costs. It also increases the complexity of the chip which increases design and verification costs. Given the current complexity of NVIDIA chips and the growth of verification effort with complexity, it should be expected that this increase is significant.

Captured Value: In the GPU market there exists only one interesting customer which could significantly hurt VIPS' bargaining position. The fact that their main competitor has already got a similar solution would however be a very beneficial point. One big problem is that there is no good way to measure the benefit from the outside. VIPS would have a significant information disadvantage during a negotiation.

Potential Value: If VIPS were to work with NVIDIA to develop products for their high end market they would be working towards a market with very high margins which would be beneficial. NVIDIA's huge budget and focus on innovation for programmability in this market also has promise for profits for VIPS.

Another great advantage is that technology introduced for the high end segment is used to create the lower end products. Thus if VIPS has benefits for the high end market, then VIPS will most likely be implemented in NVIDIA's entire product line over time. This means crossing the chasm will be an automatic consequence of getting a first visionary customer working towards a niche market. Also, implementing VIPS in NVIDIA's entire product line not only gets us into a widely used standard and crosses the chasm but also doesn't lock VIPS out of any other market since NVIDIA only produces GPUs.

6.5.4 Customized Processors

The market for customized processors is hard to evaluate since the products are, by definition, not connected to each other. While lots of custom microchip designs are being developed each year, a large portion of these only contain customized analogue circuitry (Gupta A., 2003). Since VIPS needs to be implemented on a very low level, the projects that have the resources to develop such chips are few and far between. However, a case can still be made that such projects exist and that some might benefit greatly from VIPS. This would be projects that need to enforce strict coherence under extreme circumstances, such as very high amounts of nodes and complicated heterogeneous architectures.

One such project that might be interesting is SKA, Square Kilometre Array (SKA Teleskope, 2013). SKA will be the world's largest radio telescope, coordinating antennas in both South

Africa and Australia. The amount of data generated continuously will be equal to twice the total internet traffic and the task of building the computers responsible for organizing all that data has been given to IBM (IBM Research, 2013). There are indications that coherence is one of the big challenges for that system, and it will definitely use custom designed chips (Haglund M., 2013). VIPS might therefore be able to sell or license its solution to IBM for use in SKA.

SKA proves that these kinds of projects exist, and that they are potential customers. Many companies are known to champion the development of new and very specific designs, but it should be noted that few of them gain a market or even get made at all. One market report listed 12 such projects known to be in development in 2012 (Panzer-Steindel, 2012).

Barriers to Entry: The companies and projects involved are used to collaborating with academic research that has not yet been proven. If a suitable project could be identified it is likely that they would be very interested in what VIPS can bring and very few switching costs would exist since they are creating an entirely new product.

Created Value: It is very hard to say what kind of value VIPS could bring to different projects in this category, but given their unique and demanding nature it is most definitely cases where it would be significant. One such case would be an extreme multi-core computer where scalability is a concern using today's coherence protocols.

Captured Value: Since a very specific product is targeted, a sale would be one-time only and maybe in the shape of some sort of collaboration. It is therefore unlikely that the buyers would require exclusivity of some kind. In all, VIPS would likely be in a good bargaining position within the scope of that first sale.

Potential Value: Of the active projects in 2012, fewer than half were truly customized, while the others used cores from established vendors to create highly specialized systems. While this listing was not claimed to be complete, it can still be inferred that the market is far from significant in terms of number of new projects. The market is small, but there is very little risk of trying it. A first implementation in proper silicon could pave the way into other markets, but it should be noted that this market in itself is probably not big enough to make VIPS a sustainable company.

7 Market Analysis and Recommendations

The theoretical framework and the results of the findings section are used to compare and evaluate the potential applications of VIPS. This is then used to recommend a market segment to target and to give advice on how to proceed to reach a first sale as well as suggest strategies for future company development.

7.1 Market Evaluations

To compare the markets, they were evaluated in regards to each indicator. For an easier comparison, all the relevant factors were summarized to form a general evaluation of each indicator, as shown in Table 6.

	Mobile CPU	Embedded	GPU	Customized
Barriers to entry	○	◑	◑	◕
Created Value	◔	◕	◕	◑
Captured Value	◔	◑	◔	●
Potential Value	●	◑	●	○

○ Not promising ◔ Marginally promising ◑ Somewhat promising ◕ Promising ● Very Promising

Table 6. The promise of each market in regards to the indicators.

As can be seen, there is a lot of money to be made in mobile applications but to enter this market is not viable for VIPS at this stage. The mass-market mobile CPUs are too entrenched around a dominant design and the aspects that VIPS can improve do currently not drive competition. It should, however, be noted that VIPS could potentially enter the mobile market by starting out in the lower performing embedded market. This will be explained in detail later on in the analysis.

It can also be concluded that the customized market is not a profitable target and should therefore not be a main focus. It could, however, be a possible back up plan if the other alternatives are found too hard to enter. In this case customized processors could be a way for VIPS to prove itself in a first implementation and gain funding in the process. Some caution should however be taken when negotiating with such a customer, since customized projects are likely to be long term commitments which could very well occupy valuable human resources for a long time. The primary barrier to entry would be finding a suitable project, as there are few of these and they have quite specific requirements. In the event that such a project is identified it would be worth paying attention to, but we would advise against actively pursuing this market.

Of the two remaining options, both markets could be of high interest. While less is known about the embedded market, there are more chances of finding a good fit in this segment given the wide number of applications and companies. On the other hand, exactly what benefits VIPS could provide would require more research about the verification process. Still, it looks promising enough to warrant a deeper analysis.

Out of these two, the GPU market is considered to have the highest potential for large profits. While only one potential customer exists, NVIDIA has more than enough revenues to present a lucrative long-term opportunity on its own. This would be especially true if VIPS could be implemented in a large part of their product portfolio, rather than just their specialized GPGPU-cards where VIPS would have its most natural fit. Given their history of including new features in their entire product line over time, there is good potential for such a development. Their future roadmap also suggests that this would be a plausible scenario if VIPS and NVIDIA were to negotiate a deal. This means that, when looking at the long-term potential, the GPU strategy falls well in line with the idea of crossing the chasm. In this respect it differs from the embedded market, where there might be no obvious way forward after the first sale. VIPS would risk facing a never-ending line of Normandy beaches, to use the D-Day analogy.

While there are good indications that NVIDIA would be a profitable customer if a first sale were to be made, the chances of reaching this first sale must also be taken into account. NVIDIA's focus on the growth of their ecosystem to increase the number of GPU users should be an indication that they would be interested. VIPS would make it easier to write well-functioning code, which has been a primary constraint for GPGPU usage. Neither does any significant barriers to entry exist in terms of compatibility regarding third party developers. It could however require NVIDIA to perform significant investments in development of new software and tools. Likely, the primary obstacle would rather be to prove that VIPS is significantly better than anything that NVIDIA themselves are developing in house. While they do not have a complete solution yet, it is very likely that they are working on an alternative at the moment.

As for the barriers to entry in the embedded market the there is more technical risk but given that this can be overcome the market risk is smaller. One barrier that might be harder to overcome in the embedded market is that when talking to NVIDIA it should be easier to identify the benefits at an early stage, while the embedded market likely requires a much more complete product that can be proven to provide the stated benefits. To make this complete product a reality there is a bigger need to acquire knowledge capital in the software department.

One differentiator between the GPU and the embedded market is the fact that for the GPUs the main benefit from VIPS is an enabling product improvement, while for embedded it is mainly a process enhancement. Product improvements are more easily explained and can appeal to visionaries within the companies, while the benefits of process improvements are harder to communicate. It is also harder to evaluate exactly how much a customer might gain from this implementation, which puts VIPS at an information disadvantage. This could lead to VIPS capturing less of the value created than what is possible in the GPU market.

A key benefit of approaching the GPU-market first is that only one plausible customer exists. While this could normally be considered negative, it allows for a highly focused sales effort and the ability to "fail fast". Either that one customer is interested, or the market has no potential and should not be pursued anymore. In case of the latter, this allows valuable time and resources to be spent elsewhere. To pick a strategy which allows potential failure to be quick is often mentioned as a good practice for a start-up company.

With all these arguments in mind NVIDIA seems by far the most reasonable first customer, if only because of the opportunity to quickly move on to the embedded market if NVIDIA is not interested. This market has many possible customers and there is more potential to find a perfect fit in this segment, although the process of finding such a fit requires far more work than collaboration with NVIDIA.

From the discussion above, it should be obvious that the primary benefits of implementing VIPS would be different for each potential market. Thus, it is important for VIPS to take this into account when approaching each segment. For a successful sales process, it is not enough to just present a technical solution coupled with a number of potential benefits. Rather, a focused sales argument has to be formulated which highlights the aspects that are especially important for a given market. This sales argument should encapsulate the unique benefits VIPS could provide and only focus on those aspects that are truly valued by the market. Our suggestion of such a **Unique Selling Point (USP)** for each market is (see Figure 30):

1. **GPU – Programmability:** Cache coherence increases usability and helps grow the ecosystem.
2. **Embedded - Cost reduction:** VIPS reduces cost of materials and the verification time needed to ensure reliability, while still maintaining satisfying time-to-market.
3. **Customized – Scalability:** VIPS would enable high performance for supercomputers with a very large number of cores. For other types of projects, it could be the only feasible solution to enable coherence.

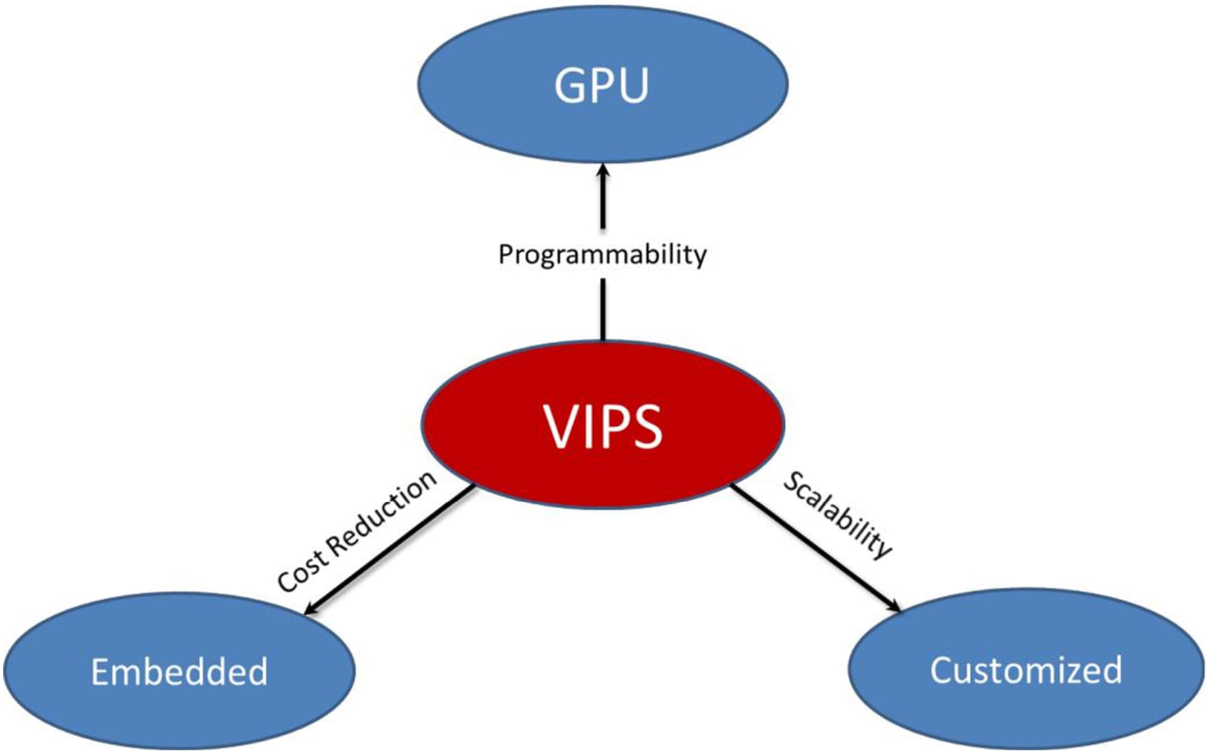

Figure 30. Illustration of different USPs for each potential market.

7.2 Recommendations

Our recommendation for VIPS is to attempt the following strategies, in order of priority. The strategies should not necessarily be executed one at a time, but available resources should be prioritized in this order.

1. **GPU:** Through continued contact with NVIDIA, license VIPS for use in GPUs with a first focus on GPGPU-programming. There, VIPS can help increase usability through simplified programming, which in turn grows the ecosystem and helps competition against AMD. If NVIDIA are interested, there is a huge potential in this market. If they are not, then VIPS should leave this market.

2. **Embedded:** Multicore embedded solutions that are not dependent on large ecosystems could potentially benefit from VIPS, especially to simplify verification. This requires a focus on process development rather than product features. If successful there is a big market, but growth will not come as easy as in the GPU market.

3. **Customized projects:** Hard to find since no true market exists, but there is likely that there are several projects that would benefit from VIPS. Should not be a priority but would be a good way for a first implementation if one were to be found.

7.3 Business case for the GPU market

To get a crude estimate of the potential for our main recommendation, a business case has been prepared. While in no way expected to give an exact figure of VIPS future earnings, it serves as guidance as to what VIPS could potentially stand to gain if implemented in NVIDIA's GPUs. The data used for the estimate are from NVIDIA's recent and projected sales figures. These data were supplemented by the following assumptions:

- **Implementation:** The first implementation of VIPS will be in 2015, considering that the next generation for 2014 has already been announced.
- **Technology adoption:** Using NVIDIA's roadmap and how they have previously included new technology "stepwise", we assume the inclusion of VIPS in the following product categories:
  - 1st generation: NVIDIA Tesla. Highly advanced cards for HPCs.
  - 2nd generation: NVIDIA Quadro. High-end cards for workstations, dedicated to GPGPU-programming.
  - 3rd generation. NVIDIA Geforce. Graphics cards for computers, primarily aimed at gaming and video rendering.
  - 4th generation. NVIDIA Tegra. SoC for mobile phones, combining CPU and GPU on the same chip.
- **Sales Prediction:** For short-term predictions, the CAGR (Compounded annual growth rate) between 2010 and 2013 was used to project sales for each product segment. Due to the uncertainty of long-term predictions, a conservative assumption of sales staying stable after the start of 2015 was used.
- **Product cycles:** Between 1999 and 2012, 12 generations of the Geforce card have been released (Poeter, 2012). We will therefore assume that a new generation of each card is released approximately once every year.
- **Product adoption:** For a specific year, the sales of a product line are divided between the latest product line and the previous generation. We will assume that about half the sales of a product line is of the latest generation.
- **Licensing and royalty agreement:** In a previous study purchased by VIPS, the consulting company TTO estimated the royalty agreements in this field to range between 2-5% of sales. Based on our analysis of the bargaining position of VIPS, covered under "captured value", we estimate this royalty to be in the lower range.

Thus we have assumed a royalty agreement of 2.5%.

- **Life Cycle:** Based on the TTO report, a 5 year life cycle is assumed.

The result is presented in Figure 31. All calculations can be found in Appendix B.

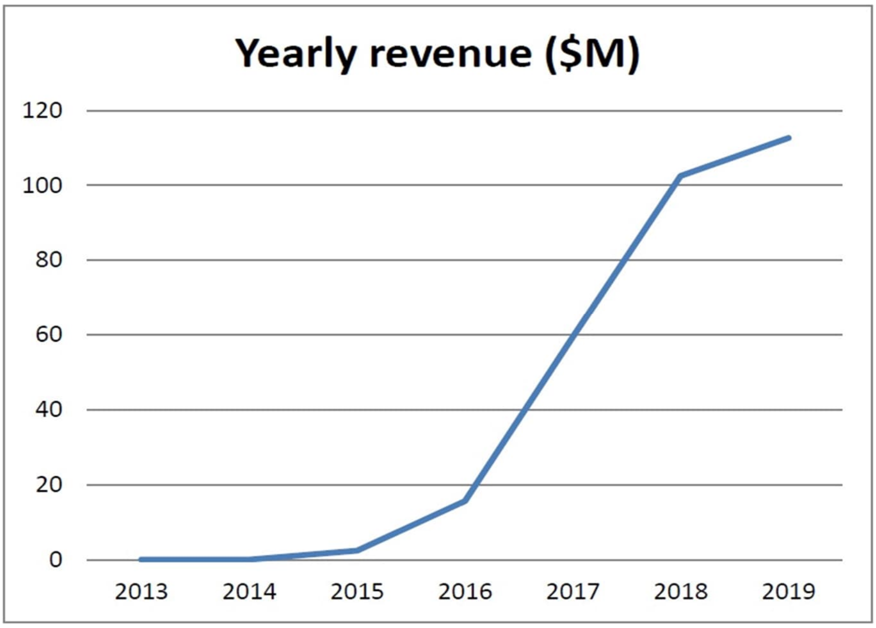

Figure 31. Estimated revenue for VIPS if fully implemented in NVIDIA's product lines.

Given the above assumptions, a very lucrative future can be projected if VIPS were to negotiate a deal with NVIDIA. While the initial sales for NVIDIA's high-end segment are significant for a small start-up, the true profits would come from getting it into their mainstream market of graphic cards for gamers.

It could be questioned though if the above projection is realistic. Most importantly, the consultancy report's proposed royalty agreement seems high given the large amounts of IP that is licensed in the industry. Our guess would be that the deal rather would be a mix between a fixed licensing fee and a smaller royalty agreement. However, since this is outside our expertise we will not delve into this further.

Regardless of the exact deal terms, the business case clearly shows the potential for profits in this market. It also demonstrates the value of getting into the mass market, as can be seen by the "hockey stick"-shape caused by the inclusion in standard GPUs. Our target to achieve this by stepwise getting included in a large part of NVIDIA's product portfolio is obviously a challenging goal. However, we think that VIPS' unique solution to solve a problem that is currently a primary focus for NVIDIA warrants such a lofty goal.

The strategy that we suggest would go well in line with Moore's recommendations on how to "cross the chasm". By finding a niche where we have a particularly good fit, we increase our chances of getting a foothold in the market while also positioning ourselves to later be able to strike the next "bowling pins" for an easy transition into the mass market.

7.4 Growing a Disruptive Technology in the Embedded Market

Entering the embedded market would go well in line with what Christensen's theory about disruptive technologies predicts. In his 2002 article specifically aimed at the semiconductor industry, he predicted that the low-end segment would shift its focus from performance towards other qualities once the performance had reached a sufficient standard. This has proven to be true for qualities such as energy efficiency, where ARM-based processors have gained significant share in low-end segments despite inferior computational capacity. Similarly, VIPS could offer improvements in areas that are not traditionally being focused on but have been gaining increased attention lately. This could be in areas such as reliability, which is crucial in medical equipment and for certain automotive applications. A simplified verification process allows for more scenarios to be tested and thus more errors being found. Other areas that could be improved would be time-to-market due to less time being spent on verification, and customization as a simpler design process allows for more chip designs to be made. Overarching all these other factors would be reduced costs, as verification is really a decision about what to test and for how long to do it.

Figure 32 illustrates Christensen's theories when applied to the micro components industry. It aims to show how the market focus has shifted from being mainly concerned with performance for all segments into more diverse customer requirements. While performance is still of great importance in the high-end segments, where companies like Intel continue to push the boundaries of the technology, the lower segments are increasingly content with the performance that they have. At the same time, the development enables new segments to be created with more specialized requirements. If VIPS can be part of a disruptive technology, by improving reliability or reducing time-to-market, it can become very competitive in this lower segment. The figure then illustrates how such disruptive technologies might evolve to reach other market segments as the surrounding technology evolves. This way VIPS could for example enter the mobile CPU market by first becoming established within the embedded market.

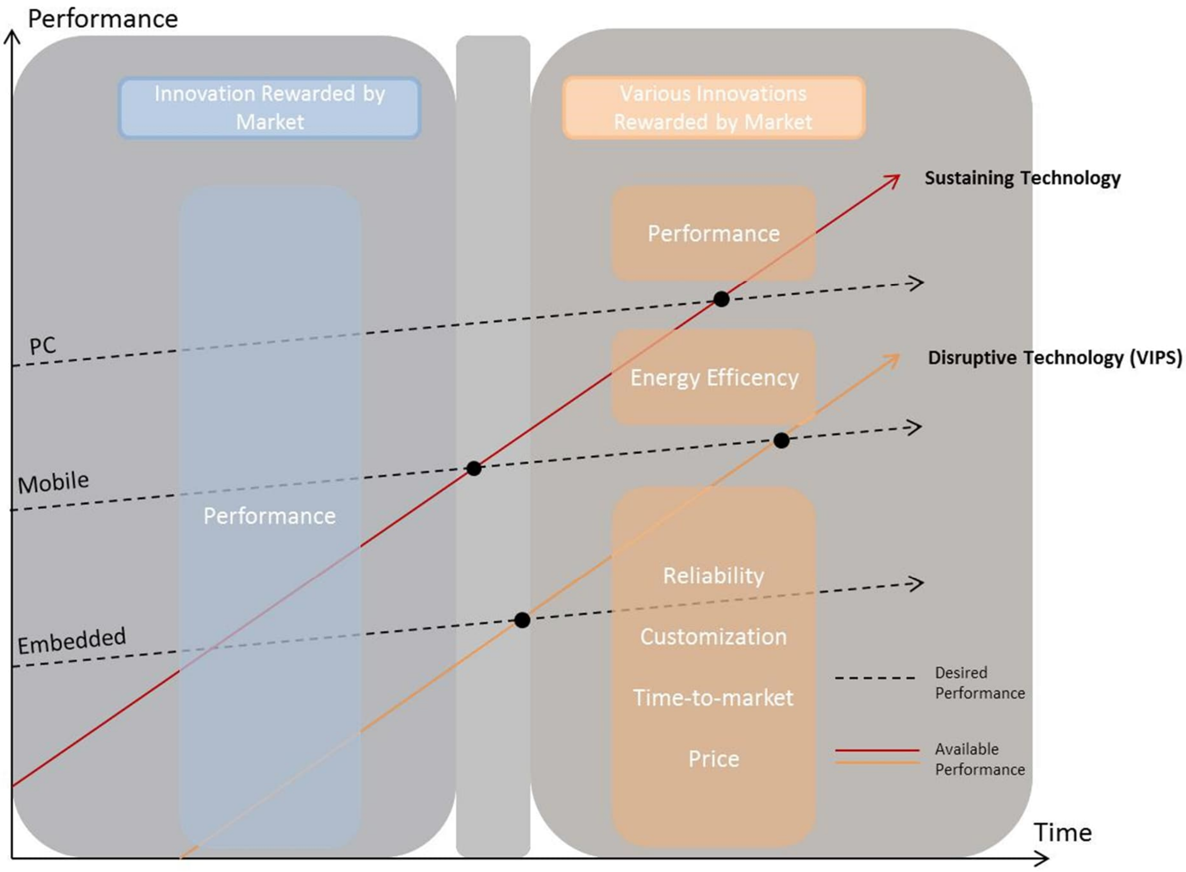

Figure 32. An illustration of how disruptive technologies can surpass sustaining ones by competing on other metrics once sufficient performance is achieved.

7.5 Recommendations for Product Development

In order to proceed with the commercialization effort, it is vital that the team starts to view VIPS as a product and identifies what is needed to develop VIPS in that respect. Understanding the process of developing new microprocessors and the costs associated with that is very important. Regardless of what benefits VIPS could possibly bring it is not interesting to anyone if they bring too much complexity and thereby added costs to the design and verification of all future products.

The benefits or problems related to verification obviously matter when targeting NVIDIA but are especially important if the focus switches to the embedded market. Here a protocol that simplifies the process might be valuable even if it does not improve the end product. For these reasons VIPS should really strive to find an answer, as general as possible, to the question of how verification costs would be affected by implementation of the protocol.

Other questions that would probably be of great interest to NVIDIA specifically are assessing the difficulty of adjusting for CUDA and OpenCL as well as potential performance improvements. The questions about compatibility with CUDA and OpenCL are best answered by NVIDIA but the person selling to them should have enough knowledge on the matter to have a serious discussion. As for the potential performance improvements, NVIDIA may not be aware of this. The best people to seek answers from are GPGPU programmers such as HPC Sweden who indicated that this might be a benefit in our interview with them.

If or when the embedded market is targeted, many questions need to be answered. Apart from verification benefits, much knowledge is needed on the software side if VIPS is to go for the embedded market. This knowledge could be acquired in a number of ways but it would probably be best if everyone had some basic knowledge. One way to gain important knowledge capital is to try to recruit engineers for the STMicroelectronics project who have a good understanding of software development tools used in the embedded market. There should also be a clear focus during this project not only to verify that VIPS will improve the STMicroelectronics products but also improve knowledge about verification in general.

7.6 Marketing and Sales

Regarding marketing NVIDIA, the most important customer, there is room for some creative marketing. One potential strategy is to engage GPGPU programmers in order to prove user demand. There are organizations and websites devoted to this topic and getting an understanding of how these customers view the potential of coherence, as well as collecting quotes from opinion leaders, could be beneficial. This could also give much better knowledge of how much programmability could be simplified. It is however important to note that NVIDIA's incentive to improve programmability is not to satisfy the needs of the current users, but rather to grow the market by getting new companies to start using GPUs for their computational needs.

Regarding sales to NVIDIA, two points seem important to take away from this report. The first is that VIPS probably cannot become a product specific implementation but has to fit well with the majority of NVIDIA products because of the structure of NVIDIA's innovation process. This means that the sales effort cannot solely focus on any one product family, such as Tesla, even if it turns out that every engineer from NVIDIA suggests that this is where VIPS has the most benefits. The second and probably most important point is that a full focus on gaining knowledge regarding what value could be offered to NVIDIA is paramount. Apart from the methods discussed above a method of trying to close a deal, or receiving funding, would reveal what interest exists or what would have to be known in order for a deal to be struck.

Regarding marketing to the embedded market, there is a need for a more comprehensive process. According to Moore, marketing of new technology should be done for the benefit of innovators but with an eye on the visionaries. This leads to a strategy of including examples from the embedded market in published papers and conference presentations with a clear focus on simplified verification when the number of cores is rather small. Another key marketing play would be to approach publications that are targeted at chip design, verification or the embedded market. This would be a great way to open the eyes of visionaries to a great opportunity to position their company using new metrics of growing importance.

Regarding the sales process for the embedded market, since little is known about the simplification of verification, this should probably be of the form used so far in all contacts. A professor visiting to discuss a new finding and currently investigating which implications this could have for the embedded market. An open ended discussion could prove very valuable in establishing contacts, acquiring further funding and learning more about what value the market places on potential process and product improvements.

7.7 Company Development

As seen in section Theory, a typical USO company goes through certain phases. The VIPS project can be seen as being in an early phase 2, as described by Vohora et al. Regardless of the formality that no company yet exists, there is still a lack of decisive entrepreneurial commitment. As shown by Olofsson et al, this commitment can take different forms for different researchers. Professor Kaxiras stated that he will continue to work within the university, which makes him a type 1 or type 2 researcher. As such, focus within the group is still much on publishing more papers, and while that can be a good way to get free advertising it is not the most important thing in order to successfully launch a product. In this case the commitment could take the shape of bringing an external CEO on-board, or similar. This step will likely be needed for the formation of the company and to give it the ability to focus on what potential customers really want.

A barrier to entrepreneurial commitment can also be the four determinants named by Nilsson et al. Out of these, the access to industrial actors and other networks are probably the most important. While many international companies that are active in the micro component industry, such as IBM, Oracle, Intel, Ericsson and Xelerated (Appendix A), have offices in the region these are mainly sales offices and little actual design work is done is Sweden (Radovic, 2013). The contacts that have been initiated with the start-up ELSIP might be seen as such industrial actors to interact with.

According to professor Kaxiras, he has a well-developed network of contacts that could be used to recruit the competence needed for the company. If that is the case then it looks very promising for the future development, but otherwise this is an issue that will need to be resolved before the project can progress further.

8 Discussion

In this section we discuss the methods employed and give answers to the fundamental questions of the study as well as discuss the ethics of the project.

8.1 Market Research

Steve Blank emphasizes the importance of actually talking to customers when doing market research for a start-up. While he recognizes the value that quantitative data can bring he says that until you have seen “the light in a customer’s eyes”, you do not know if you have a hit. In Crossing the Chasm, Moore advises new start-up owners to trust their intuition when making decisions on which market niche to target, intuition which is supposed to be built by talking to the users of your product. It is clear that both of these authors consider qualitative research to be the way to understand what your customers value and what they feel about your product. Still, the question arises how to measure the quality of your data and conclusions.

The standard ways to measure the quality of a quantitative research is validity; how closely the questions asked relate to the purpose of the research, and reliability; the variation in the data sampling process. (Golafshani N., 2003) notes that using these measurements for qualitative research has been widely discussed and much critique has been raised. Validity and reliability are very well fitted for a mathematical analysis of a data set but according to Golafshani, many qualitative researchers claim that these are very difficult to address in a qualitative study. She also notes that triangulation, the method of collecting related data and establish whether the sets of data conform, needs to be adapted to qualitative research evaluation.

(Golafshani N., 2003) discusses different measurements used to determine the quality of qualitative research. She argues that validity and reliability need to be broken down into concepts more suited for the qualitative research paradigm. (Lincoln Y., 1985) propose a different set of concepts. These are credibility of the sources (related to reliability), neutrality of the sources and applicability of the information (related to validity) and consistency with other known sources (related to triangulation). These are the measurements to be used for evaluating the method in this report.

The interviews conducted can be divided into two categories for analysis. The first category is executives in potential customer companies and the second category contains general industry experts, users further down the value chain and third party developers. As the first category of interviewees are decision makers at customer companies they have very high credibility, which means that they know what the important drivers are for their company. Regarding the second category, the credibility is not as impressive, which is why these sources are not referenced for important points without backing up the claims with more credible data from other sources.

Regarding neutrality there are some problems with the first group. One way that has been used to get past this issue has been to emphasize that we are students wanting to understand more about the drivers that exists for their company rather than salesmen for VIPS. Still there is an issue that they might very well start negotiation tactics regarding any new invention they are presented with. In the cases where the answers have been very dismissive and definite we can conclude that this is not the case but where the answers have been more open ended, there seems to be no way to be sure of their intentions other than attempting to get a sale or request funding. This is a strategy to get information suggested by Blank, but one that the authors did not have permission to use from VIPS. In the second group there is no need for misdirection and the neutrality was deemed to be very high.

Regarding applicability of the information the first group ranks very high. Their statements during a discussion about VIPS were rarely completely inapplicable to the question of which market segment to choose. There is however the problem of choosing the right questions which is discussed in more detail below. The applicability in the second group is far lower and many sweeping statements were gathered. These statements were judged on an individual basis and the statements that seemed inapplicable were simply not included in the report.

Consistency with other sources was in general very high. During the indicator creation and analysis phase, secondary sources such as other interviews and industry reports were consulted to ensure a high consistency. Statements that did not conform to more than one source were not used except in the cases where a potential customer was completely dismissive.

One shortcoming of this method is the process of formulating questions, which constitutes an applicability problem. This process was heavily influenced by the interviews and there may well be some bias towards talking about the subjects the interviewee is interested in on a personal level instead of discussing the actual drivers. The data might therefore be somewhat biased in what is emphasized. To get around this problem we used several, though imperfect, techniques. One was to have bi-weekly meetings with the project owner, Mateo Santurio, where we were given direction and help to focus on the most important aspects. Another was to review company websites and listen to presentations, many at DATE 2013, to better guide us towards drivers rather than topics of personal interest of the interviewees. Other methods which have been suggested is to adopt an ABC (Always Be Closing) strategy where the interviewee is put on the spot to really answer the question of why a sale is not likely. Another rather opposite strategy is to not present the product but rather talk generally about drivers and the basis for past decisions. This strategy was sometimes applied, but could have been utilized to a far larger extent.

Another problem is lack of technical expertise among the interviewers. With more understanding of the technology it would have been easier to quickly relate the industry drivers to potential benefits of VIPS. One important driver was discovered and related to unevaluated technical aspects, namely simplified verification for new products. If verified this may be a way that VIPS could reduce the cost of designing new chips, something generally called a process improvement. This aspect had previously not been considered by the involved parties and provided the potential for a new USP. With a deeper understanding of the subject, there is a potential that more such aspects had been recognized.

The methods employed and suggested are easily generalizable to market research for any disruptive innovation in a B2B market. As noted in the beginning they also relate very well to practical industry knowledge as formulated by Blank and Moore, much respected industry profiles. In summary the suggested additions to a qualitative market study for determining the most suitable application of new technology are:

- Maximizing credibility by interviewing potential customers.
- Overcoming neutrality issues by using an ABC method or by not presenting the product.

- Improving applicability by listening closely to customers, using an iterative process between technical and market research and consulting experienced generalists.
- Checking consistency whenever a question is important to the decision making process.

8.2 Market Segmentation

Using the terminology proposed by (Cortez R., 2020) we conceptualized the market as a changing market and the segmentation as a discrete event. In the pre-segmentation stage researchers answer the questions “what is the market?” and “what is the purpose of the segmentation?” We defined the market as a technology-application space, which is common among researchers doing B2B market segmentation for new technologies. The purpose of the segmentation falls into the second category described by (Cortez R., 2020), namely “identifying target segments and planning future product offers”.

We used a break-down, posteriori approach which is not seen in any of the articles reviewed by (Cortez R., 2020). This means that we started from a view of the entire market, rather than starting with a view of individual applications, and then tried to separate it using variables which were not defined at the start of the project. While this approach is obviously possible, neither Cortez nor any of the other researchers reviewed consider it an option. Most qualitative methods are based on a break-down approach which means we did the same as most researchers in this respect.

In retrospect the break-down approach was chosen without any reflection on other options and without reviewing the literature. It seemed natural to start with a view of the market as a whole, rather than starting with individual companies, because that is how we started to learn about the microprocessor industry. Had we started learning about microprocessors by studying individual actors in the industries then it likely would have been more natural to create market segments using a build-up approach. It was likely a mistake to start in this way and it could have been avoided by studying the B2B market segmentation literature beforehand. It should however be noted that we likely would have arrived at the same place because in the end the market was broken down so far that we were left with individual companies and very specific applications.

In segmenting the market for VIPS we relied on three principles. All potential customers in the segment should have similar drivers, require a similar R&D strategy from VIPS and be sufficiently large to sustain the startup. These are justified in the methodology section. While the final segmentation looked similar to what you might expect from a standard characterization of products it was not in fact very similar at all. In fact, none of the three recommended segments are segments you would get from a straightforward segmentation based on application.

The recommended segment “GPU” has been sliced to only contain GPUs used for GPGPU. The segment “embedded” was recommended as the second priority and was discovered as a segment which fit the criteria without having a clear counterpart in a straightforward segmentation based on products. The third recommended segment was “Customized Processors” which includes products that would ordinarily be included with HPCs and embedded processors.

The same is true for the segment HPC which was sliced down to contain only the part of those products which had different drivers from other segments. The segments CPU and MPU both contain products that don’t tend to be classified with the rest of the segment but have been included based on the criteria for segmentation.

The criteria for market segmentation proved very useful for following phases since questions about strategy could be answered in the same way for entire segments. For example, it would be impossible to target the embedded market as traditionally defined. The drivers for processors in mobile phones are completely different from the segment defined in this report and the strategy to target that market as a whole would necessarily only work on parts of the segment.

There is some reason to consider a fourth criteria based on the literature reviewed before the project. In “Crossing the Chasm” Moore advices entrepreneurs to choose a market niche where their sales can easily translate to more sales and ultimately to market dominance. The method used for segmentation does not take that into account and a start-up might find itself being standard in parts of a segment without any translation into the rest. A fourth criteria might thus be “Adoption of new technology by parts of the segment tend to translate into adoption across the entire segment”.

This criteria was excluded for many reasons. One was that a single sale was predicted to be very large and this makes it more important to find market segments where that was likely. Another reason was that there are very few potential customers in every segment so VIPS is likely to target all of them individually after preparing to target the segment. A third reason was that the potential customers are involved across many segments and VIPS may find that the best way to move forward following a first sale would be to develop the technology for other products for the first customer.

8.2.1 A Relationship Marketing Approach

According to the criteria suggested by (Freytag P., 2001) the microprocessor industry is a perfect fit for a relationship marketing approach since it has all of the relevant characteristics of close cooperation, highly adapted products, strong bonds and high switching costs.

The relationship approach in market segmentation may include segmenting based on such factors as general attitude towards collaboration, amount of adaptation required by supplier or customer and commitment needed. While none of these factors were explicitly mentioned as segmentation variables both the adaptation required and commitment needed were included in the considerations. Attitude towards collaboration was not taken into account in the segmentation but was included in the segment evaluation stage.

For example the segment named “Customized Processors” was sliced of from HPCs and embedded processors since both commitment needed and adaptation requirements were varied across those segments. This was justified as a difference in needs as well a difference in R&D strategy required but was likely best conceptualized as a difference in customer adaptation requirements.

8.2.2 Organizational Buying Behavior

(Johnston W., 1996) finds 13 factors in the organizational buying behavior literature which determine how buying decisions are made. Individual factors, group factors, conflict/ negotiation factors and role stress factors were excluded from consideration during the market segmentation stage. This seems appropriate since they requires a very deep and granular understanding of the individuals involved. Segmenting based on such factors may be appropriate when existing relationships exist but for this stage of the project it would require much more resources than was available. Here follows a list of the remaining factors and how they relate to the market segmentation done:

- Environmental factors such as the legal, technological and related market factors were extensively investigated and played a major part in the market segmentation. This seems entirely appropriate as they were often found to create various barriers that forced sections of the market to be excluded.
- Organizational factors such as the goals and structure of potential buyers were central to the market segmentation for obvious reasons.
- Product factors were central to the marketing segmentation in an obvious way and this seems appropriate.
- Seller factors were applied to the segmentation process as a limiting principle. Applications where the sellers would require different resources, usually resources that could be acquired through expensive R&D, were placed in different segments. This seems reasonable since part of the purpose for the segmentation was to find segments that could be approached with one single development strategy motivated by the limited resources of the seller.
- Not taking informational factors and network communication factors into account for the market segmentation is likely a big oversight of this project. Part of the purpose of the segmentation was to create segments that could be approached by a single marketing strategy and making sure that each segment would respond similarly to similar messaging was a major part of the segmentation. How these marketing messages would reach customers was not taken into account and it is entirely possible that there is great variation within segments and great uniformity between segments. This creates a risk that the marketing strategy deployed misses parts of a segment and that the marketing reaches customers of different segments with bad messaging.
- Process factors and decision rules factors were not taken into account for any part of the project. This is likely a mistake but it is hard to say since very little is known about the processes or decision rules potential customers have for deciding on a purchase.
- Buyer-seller relationship factors were not taken into account. It may have been possible to use the existing relationship with STMicroelectronics as part of the segmentation since this relationship does affect potential marketing strategies. Also informal relationships with employees working for potential customers could have been considered but such relationships were not investigated.

(Chanler J., 2012) identifies a trend in the organizational buying behavior literature to view organizational buying as an integrated part of innovation, design and marketing processes. This was a perspective we certainly took during the project by (1) interviewing users and third party developers of potential customers, (2) trying to get a deeper understanding of how VIPS would fit into existing technology and product portfolios of potential customers as well as (3) how a purchase would change their innovation process by allowing for process improvements through simplified verification and (4) how it would allow for new products like coherent GPGPUs. This perspective proved absolutely crucial in all stages of the project and a failure to adopt this perspective would have meant that none of the segments would have been the same and the advice to VIPS would have been largely unusable.

8.3 Market Segment Evaluation

The market segments were evaluated using the indicators “Barriers to Entry”, “Created Value”, “Captured Value” and “Potential Value”. These do share some similarities with the metric used in (Hlavacek J., 1986), which is based on (1) market growth potential, (2) The level of market domination by large and powerful competitors, (3) Entry barriers and the ability to reach critical mass by the producer and (4) the value added by the producer. “Value added” is identical and the “barriers to entry” indicators are the same except for the difference that Hlavacek includes the ability to reach critical into this indicator. “Potential value” is similar to “the market growth potential” with the difference that we include the ability to reach critical mass into this indicator instead of barriers.

The big difference is that we use the “value captured” indicator and don’t use the market domination of a large and powerful competitor. One reason not to include competition into our attractiveness metric is that there is no entity which competes with VIPS. Competition from a broader perspective can be seen as “using traditional methods”, “inaction”, “in house solutions” etc. Since competition isn’t a formal rival we have included these alternatives into other indicators such as “entry barriers” or “value added”.

The inclusion of the “value captured” indicator, which is absent in (Hlavacek J., 1986), seems very appropriate for a number of reasons. Hlavaceks model assumes that added value can be transformed into captured value in a way that does not vary sufficiently between segments to warrant its own indicator. Instead it comes in only as a type of barrier in the “ability to reach critical mass” part of the “barriers to entry” indicator. In this study we have discovered segments with varying difficulties in assessing value added leading to varying difficulties in capturing the value created. There is also vast power imbalances between VIPS and its potential customer resulting in a difficulty to capture value, thus making the ability to capture value heavily dependent on the business practices within the varying segments.

This is an area where organization buying behavior theory could have played a bigger part in the segment selection. When assessing the ability to capture value in the various segments it would have likely been rewarding to consider both informational factors as well as the processes by which the various potential customers make purchases. Also potential buyer-seller relationships should have been investigated and such factors should be included somewhere in the attractiveness metric.

Drawing on the relationship marketing theory we did start from a point of view “proactively creating, developing and maintaining committed, interactive and profitable exchanges with selected customers [partners] over time” was the main goal, making the relationship marketing theory perfectly applicable. As suggested by (Lages L., 2005) this would involve marketing by improving "relationship policies and practices, trust in the relationship, relationship commitment, mutual cooperation, and satisfaction with the relationship". The ability to create and maintain such relationships can be included into the attractiveness metric in place of such blunt indicators such as barriers to entry, value created and value captured. An alternative attractiveness metric using this approach may be (1) difficulty to form a first buyer-seller relationships, (2) likely long term mutual satisfaction with such a relationship, (3) potential profitability of such a relationship and (4) growth potential as a result of first sale.

Typical relationship marketing concepts such as "attitude towards collaboration", "commitment needed" and "buyer/seller adaptation needed" would be included into this metric under the difficulty to form a first relationship as well as the long term mutual satisfaction. Any existing relationships between the individuals involved would also fit neatly into these indicators. The ability to leverage a first relationship in the way suggested by Moore in the "D-day analogy", described in 2.3.4, would naturally be included into the growth potential resulting from a first sale.

One problem with the division used in this study was that the significance placed on these indicators was far different. The "barriers to entry" were far more important than the others given the limited resources of the project and the relatively large barriers in all segments. Created value was also important as this would indicate the willingness of a potential customer to partner with VIPS to develop the technology.

The captured value ended up very marginally playing into the final recommendations as any sale was likely to significantly help development and capture enough value to sustain the project in some form. The potential value of a full segment was also not of great interest since every segment was large enough to create a sustainable and scalable business model. Thus the connection between the indicators created and the decisions they were meant to guide were not as clear as they perhaps could have been.

8.4 Ethics

(Bryman A., 2007) presents a breakdown of the main ethical principles often discussed in relation to business research into four main areas:

- Harm to participants
- Lack of informed consent
- Invasion of privacy
- Deception

Harm to participants is often discussed in very broad terms and often include such consequences as reputational, career or mental consequences. The category is so broad as to sometimes involve the participants learning something about themselves which they would have wished not to know. This makes it impossible to avoid potential harm during studies and the ethical discussions tend to revolve around harms that seem likely to the researchers or third parties tasked with reviewing the project. While there is some discussion surrounding the experience of being a participant in a project, such as in the discussion surrounding the Milgram experiment, the main topic discussed in (Bryman A., 2007) seem to be the issues arising from a potential lack of anonymity. In other words, the discussion centers on the consequences of releasing what is found about a specific person or organization.

There is wide agreement that anonymity of participants should be protected but some have argued that this is not always the case. Some participants may wish to have their names included as a recognition of their participation. The sources in business research can include varied participants and may include quotations that are expected to come along with credit to the person who said it. In this study, for example, we include answers given by an industry executive during a public Q&A session. As the answer is intentionally made public by a participant as part of their job duties it would be problematic to quote them without giving credit.

The harm to participant area of discussion is often tied closely to the lack of consent area since it is seen as more "ok" to risk harm to participants if they give informed consent to participate. As an example we return to publishing an answer given during a Q&A session. It is entirely possible that this executive said something that cause them harm once it is published but in this example the executive is generally seen as having given informed consent for their statements to be published when they make the statement publicly.

In more private settings, such as an interview, it becomes less clear what consent is given. According to the AoM code of Ethical Conduct informed consent means "explaining to potential participants the purposes and nature of the research so they can freely choose whether or not to become involved". It has however been noted that it is impossible to fully inform on the nature of the research and as such it is impossible to get fully informed consent. One example mentioned in (Bryman A., 2007) is that the researcher might not correctly inform the potential participant on the time the participation might take. This is also brought up as a potential place where researchers intentionally avoid informing the participant or even intentionally misinforming participants in order to encourage participation.

Invasion of privacy concerns relate to the researchers finding information that the participant wishes not to be known. When people chose to be interviewed they may decide that certain areas are private to themselves or the organization they represent. Since these areas are impossible for the researcher to anticipate it is recommended, for example by the Marketing Research Society Code of Conduct and Guidelines, that the researcher "treat each case individually, giving respondents a genuine opportunity to withdraw."

Deception is generally thought of a tactic that should be minimized, not least because it undermines informed consent, although there are many who take an "the ends justify the means" approach. They argue that deception can be used when a result cannot be found without it given that the research is sufficiently important. According to the Social Research Association Ethical Guidelines it is the duty of researchers "not to pursue methods that are likely to infringe human values and sensibilities".

Another ethical considerations raised by (Bryman A., 2007) are that it can be seen as unethical to waste time or resources and as such it is thus unethical to produce low quality research if such research takes resources to produce. They also argue that researchers should think of their research as a collaborative enterprise that benefit both the researchers and the participant either directly or in a moral sense where the participant is helping a research endeavor which they would like to help for moral reasons.

This paper does not anonymize any of the participants who have chosen to participate and the authors have not taken any explicit precautions to avoid potential harms of those interviewed. The reason for this is that all the information used is either already public or has been freely given by people as part of the participant's job duties. During the interviews we have informed participants about the general nature and purpose of the project even if the exact nature of the VIPS technology has sometimes been withheld. We see this as ethically justifiable because the identity of the participants have been very important to the study itself and in all cases the participant has given us information as part of their job to publicize information.

When it comes to potential harms that this may cause the participants it is likely to be seen as harms that results from them making a mistake while doing their job. If a participant had said something they regretted we would have been willing to strike such a statement but such a situation has not come up. Generally the participants have shared such information that they are allowed and encouraged by their employer to share, or that they believed that their employer encourage them to share. Considering these factors the upside of crediting participants for their contributions have been judged to outweigh the potential downside of publicizing their names.

We have employed tactics of intentionally misrepresenting the time an interview might take and applied modest amounts of social pressure to encourage participation. This can be seen as unethical, especially if the participant gets nothing out of their participation. There is however some justification for these practices, since the purpose of the project ultimately has been to discover and meet the needs of the interviewees and their participation should be seen as a collaboration for mutual benefit. Still, in retrospect these practices were not ethical and constitute what (Bryman A., 2007) calls a minor transgression that probably pervade most business research.

An unrelated ethical issue which arose during the study was that there were some problems regarding to the interests of various stakeholders. The project owner who requested this report was VIPSs partner UUAB who are state funded and have interests in both the profits of the company and the potential benefits for the Swedish economy. The VIPS founders on the other hand were interested in both the potential profits but also had a strong interest in the technology being adopted.

Thus the stakeholder interests were not entirely aligned which is not unusual according to Mateo Santurio, the project supervisor at UUAB. This can cause problems when choosing methods as well as suggesting strategies. The method employed to address this was to focus on the mutual interest of profitability for the company. Any potential effect on the Swedish economy as a whole as well as the potential to get the invention used without profits were thus ignored.

As the separate interests of the stakeholders were rarely expressed explicitly and only occasionally alluded to there was little conflict. To ensure a good cooperation we made our intentions and methods clear to all stake holders and made recommendations based on their shared interests.

9 Conclusions

This report contains a case study of the type called for by (Cortez R., 2020) and makes contributions to the conceptual, applied and technological challenges in the segmentation task as called for in the literature review by Cortez et. al. Many of these contributions are gathered and presented as a model for this type of research in the next section. The report is also meant to serve as a decision basis for VIPS and contribute to VIPSs continued development.

This report shows that there is definitely enough potential for VIPS to warrant a continued commercialization process. However, it is important to soon get a focus on product and company development rather than on further research. To do this, a few key markets should be targeted to gain further understanding on how to develop the product to meet needs specific to that market. This report contains recommendations on how a first step towards such a focus could be taken.

To help with the further development of VIPS, this report has the following main contributions according to the authors:

- Segmentation of the market into groups that have similar drivers and would require a similar strategy of approach.
- Evaluation and disqualification of three of the markets that were originally envisioned by the inventors - HPCs using standardized CPUs, APUs and mobile.
- Identification of NVIDIA as a key customer, as well as the formulation of a strategy for how to approach them.
- Identification of the potential for VIPS to simplify chip verification and that there is a market demand for such simplification.
- Highlighting the importance of developing VIPS as a product for needs specific to key market.

9.1 An alternative market research model

In this section we synthesize knowledge described in this study drawn from market segmentation theory, organizational buying behavior, relationship marketing theory as well as the start-up and USO literature and the field experience to suggest an alternative model for market research and segmentation for a start up with new technology in a B2B market characterized by high amounts of cooperation and adapted products. One should first note that these circumstances are frequently true for USOs as long as the new technology is meant to fit into an existing and complex ecosystem. This section relies heavily on sections 2, 3 & 8.

Conceptualizing the market as an application space of competing technologies or technological applications is common in the business market segmentation literature when segmenting for a new technology as it helps firms understand the place for their technology. The market can be thought of as either static or dynamic and the segmentation may be thought of as either discrete or continuous, as described in 2.2 by (Cortez R., 2020), depending on the nature of the market and the segmentation project. In the case of resources being relatively limited there is good reason to view the market as static to reduce market complexity and to view the segmentation as a discrete event to limit the scope of the project. Once a preliminary view of the point of the market and the segmentation project has been decided we suggest using the model visualized in figure 1 and described in section 3.

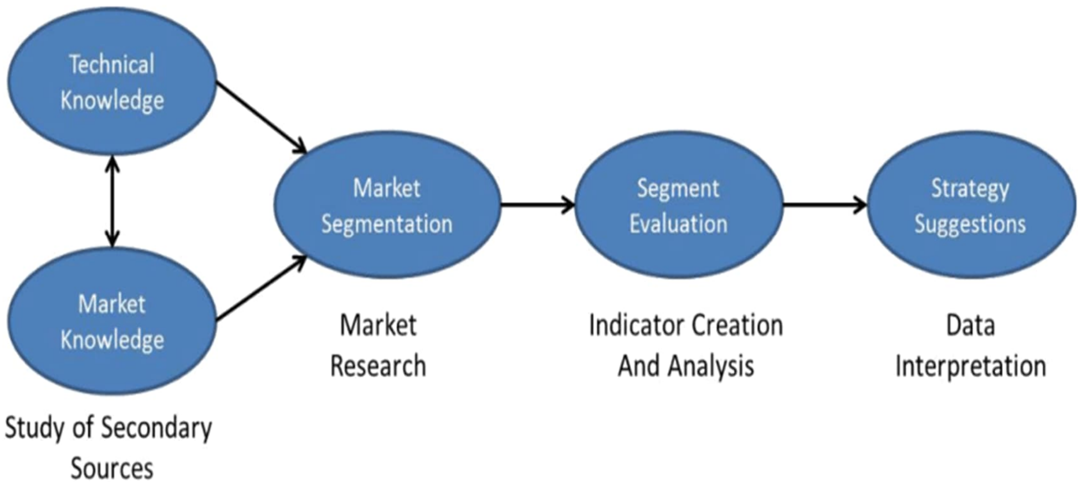

Figure 1. The main phases suggested. The purposes of each phase in the bubbles and the work done during the phases is presented underneath.

During the study of secondary sources it is recommended that the researcher tries to create a model of the entire value chains where the relevant technology is used. Using VIPS as an example the value chain includes microchip designers, chip manufacturers, microchip sellers, those who design and assemble products including microchips, sellers of such products, buyers of such products (consumers and organizations), users of such products (consumers and organizations) and sellers of related products (such as game developers etc.).

During the market research phase there seems to be broad agreement from the start up literature, the literature on selling disruptive technology and from the business market segmentation literature that qualitative studies are most appropriate for this situation. This also tracks with the experiences from this study. During this process the researcher should attempt to gain an understanding of the main drivers at various places in the value chain but pay extra attention to the companies that could be future customers.

To judge the information gathered during the market research phase we suggest using the concepts described in 8.1 and suggested by Lincoln and Guba (1985). These are namely credibility of the sources, neutrality of the sources and applicability of the information and consistency with other known sources. We reiterate the advice given in 8.1:

- Maximize credibility by interviewing potential customers.
- Overcome neutrality issues by using an ABC method or by not presenting the product.
- Improve applicability by listening closely to customers, using an iterative process between technical and market research and consulting experienced generalists.
- Check consistency whenever a question is important to the decision making process.

For the market segment creation there is good reason to use a build-up postiori approach as described in 8.2. A metaphor often used for the build-up approach is that it doesn't start with the forest but views each tree separately and then lumps trees together into segments based on their similarities while the postiori approach means that we don't know beforehand which types of similarities will eventually be used to lump trees together. This approach is not seen in the market segmentation research even though it is commonly recommended in the start-up literature (e.g. Blank and Moore).

As for the segments themselves they should (1) have potential customers which can all be successfully reached by a single marketing strategy, (2) require the same R&D strategy to satisfy the needs across the segment and (3) be large enough to build a repeatable and scalable business model within each segment. If a potential segment has diverse needs or require diverse R&D strategies then a portion of the segment need to be removed. If a segment isn't large enough to sustain a repeatable and scalable business model then it needs to be expanded to include other applications. If it is not possible to include a potential application into a segment that fills these properties then that application can be disregarded. It should be noted that these three criteria are similar to those presented in 3.2 but with influences gathered from organizational buying behavior theory described in 2.2.4. This inclusion is justified in 8.2.2.

During the market research phase it is also recommended that researchers draw on the trends in organizational buying behavior described by (Chanler J., 2012) to view organizational buying as an integrated part of innovation, design and marketing processes. This is a good way to analyze the impact of a purchase for the entire organization of a potential customer and not miss potential process improvements or other benefits the customer would receive.

During segment evaluation stage of the process it is customary in the B2B market segmentation literature to create an attractiveness metric composed of a number of indicators as discussed in section 8.2. Drawing on relationship marketing theory along with the theory examined in 2.3.4 & 2.3.5 as well as the experiences of this project we recommend the following indicators:

1. Difficulty to form a first buyer-seller relationships.
2. Likely long term mutual satisfaction with such a relationship.
3. Potential profitability of such a relationship.
4. Growth potential as a result of first sale.

Drawing on relationship marketing theory researchers should include concepts such as "attitude towards collaboration", "commitment needed" and "buyer/seller adaptation needed" this metric under indicator 1 & 2. Drawing on organizational buying behavior theory researchers should include informational factors (what information impacts the buying decisions inside the segment and where is that information taken from) as well as the processes potential customers within the segment use to make buying decisions. Also potential buyer-seller relationships should be investigated and such factors should be included in the assessment of indicator 1 & 2.

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11 Appendix A

List of contacts:

Company	Name	Title	Date of Meeting	Description
ARM	John Goodacre	Director of Technology and Systems	18-22 march 2013	Goodacre was a keynote speaker at the DATE conference and we spoke to him several times about the mobile CPU business and their opinions on new technology and university research.
Bull	Eric Monchalin & Pascale Rosse-Laurent	Head of extreme computing R&D	21 march 2013	Bull is a manufacturer of HPC systems. We met with them in Grenoble during the DATE conference.
ELSIP	Adam Edström	CEO	18-22 march 2013	ELSIP is a university spinout from KTH that has a product that also addresses cache coherence. We met with them during DATE and we agreed to keep further contact. Because of tight scheduling another meeting has not yet been held.
Ericsson	Christian Govella	Verification Engineer	April 26 & May 17 2013	Spoke over telephone about verification problems. He was interested in a more formal interview but no time could be found.
Freescale Sweden	Ulf Bragnell	Program Manager	Mail contact only	Freescale design chips for the embedded market. They expressed an interest in hearing what the VIPS project was

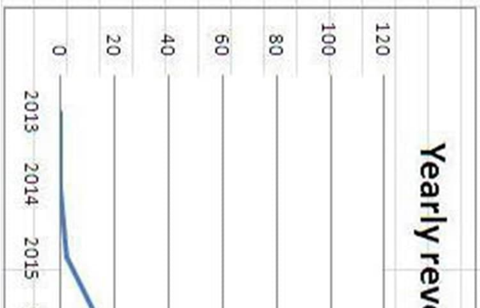
				about but despite several attempts at scheduling a meeting it unfortunately never happened.
HPC Sweden	Ian Wainwright & Jimmy Pettersson		12 April 2013	HPC Sweden is a small consulting firm specializing in GPGPU-programming. They presented us with a good understanding of the GPGPU market and its dynamics.
IBM	Mikael Haglund	Chief Technologist, Sweden	15 march 2013	Had a meeting at IBM's office in Kista. He explained how IBM works with new technologies and gave an overview of current projects, including SKA.
Oracle	Zoran Radovic	Principal Engineer	5 April 2013	Radovic is an alumni of Uppsala University and is currently working for Oracle in Stockholm. He has read the papers and could give a useful second opinion on the technology.
SP Devices	Tomas Wolf		15 March 2013	Tomas Wolf has worked with start-ups in the semiconductor industry for a long time and has been asked to join the VIPS advisory board. He gave insight into the difficulties of such a project.
Synopsys Solutions Group	Joachim Kunkel	Sr. VP GM, Solutions Group	21 March 2013	Synopsys is a large vendor of semiconductor IP and verification tools. We had an interview with Kunkel during DATE in order to learn more about the verification problems facing new chips.
Uppsala University	Erik Hagersten	Professor	Mail contact only	Hagersten has much experience from the industry and have been an adviser for the VIPS project. He did not think he had much input for us, but directed us towards other interesting contacts.
Verification Group	Carl Leonardsson, Zhu Yunyun & Mohamed Faouzi Atig		25 April 2013	The formal verification group at Uppsala University has assisted Kaxiras with a formal description of VIPS. We talked to them to get a better understanding of how VIPS could impact chip verification.

Windriver	Håkan Zeffer	Senior Member of Technical staff		According to Carlström, Zeffer is a leading expert in cache coherency. Talking to him would have been very helpful but unfortunately he had to decline due to a tight schedule.
Xelerated	Anonymized	Architect of Chips, Networks and Computer Systems		One of a few chipmakers from Sweden, we were recommended to talk to them by Zoran Radovic. When we contacted them they did not have time, so no meeting was held.

Except for the above mentioned people contact was initiated with about 10 other companies with whom no meetings could be scheduled.

12 Appendix B

	A	B	C	D	E	F	G	H	I	J	K
1											
2	**NVIDIA Sales**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**		**Growth**	
3	Tesla 1	115	193	193	193	193	193	193		Tesla CAGR 2010-2013	6
4	Quadro 1	750	863	863	863	863	863	863		Quadro CAGR 2010-2013	1
5	Geforce 1	2400	2640	2640	2640	2640	2640	2640		GeForce CAGR 2010-2013	1
6	Tegra 2	540	810	810	810	810	810	810		Tegra CAGR 2012-2013	5
7										**References**	
8	**VIPS**										1 Kar
9	Royalty	2,50%									2 GTC
10	Adoption	50%									
11	**Revenues**										
12	Tesla			2	5	5	5	5			
13	Quadro				11	22	22	22			
14	Geforce					33	66	66			
15	Tegra						10	20			
16	**Yearly revenue ($M)**	0	0	2	16	59	103	113			
17											
18	**Cumulative Revenue**	0	0	2	18	77	180	293			
19											
20											
21											
22											
23											
24											



Calculations for the NVIDIA business case